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THESIS

LIGHTENING THE LOAD OF A USMC RIFLE PLATOON THROUGH ROBOTICS INTEGRATION

by

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June 2014

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With the increase of the loaded weight that a Marine carries, the integration of robotics is a significant point of interest to the United States Marine Corps, especially to the Expeditionary Energy Office. Through the use of the agent-based modeling and simulation application, Pythagoras, robots are integrated into a Marine Expeditionary Unit's rifle platoon to alleviate the burden on each Marine. This study examines the rifle platoon's energy and power consumption, operational reach, and operational effectiveness for a scouting and patrolling mission. A systems engineering methodology results in a tradeoff analysis on the rifle platoon's success, relative to the number of integrated robots. Integrating six robots in a rifle platoon can improve the platoon's ability to fulfill its mission, while supporting the Marine Corps' energy strategy. In the context of energy initiatives, this research forms the baseline for investigating the impact of robot integration in Marine combat operations through simulations.

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LIGHTENING THE LOAD OF A USMC RIFLE PLATOON THROUGH ROBOTICS INTEGRATION

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ABSTRACT

With the increase of the loaded weight that a Marine carries, the integration of robotics is a significant point of interest to the United States Marine Corps, especially to the Expeditionary Energy Office. Through the use of the agent-based modeling and simulation application, Pythagoras, robots are integrated into a Marine Expeditionary Unit's rifle platoon to alleviate the burden on each Marine. This study examines the rifle platoon's energy and power consumption, operational reach, and operational effectiveness for a scouting and patrolling mission. A systems engineering methodology results in a tradeoff analysis on the rifle platoon's success, relative to the number of integrated robots. Integrating six robots in a rifle platoon can improve the platoon's ability to fulfill its mission, while supporting the Marine Corps' energy strategy. In the context of energy initiatives, this research forms the baseline for investigating the impact of robot integration in Marine combat operations through simulations.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAV	assault amphibious vehicle
ACE	aviation combat element
BLT	battalion landing team
CLB	combat logistics battalion
CLT	company landing team
CONOPS	concept of operations
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	design of experiments
E2O	Expeditionary Energy Office
E2W2	Expeditionary Energy, Water and Waste
EW12	Expeditionary Warrior 2012
GCE	ground combat element
HCI	human computer interface
HRI	human robot interaction
IED	improvised explosive device
JOAC	Joint Operational Access Concept
LAV	light armored vehicles
LOS	line of sight
LS3	Legged Squad Support System
M3	Maximum Mobility and Manipulation
MAGTF	Marine Air-Ground Task Force
MANA-V	Map Aware Non-Uniform Automata-V
MAV	micro air vehicle
MEAT	Marine Energy Assessment Team
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MCWP	Marine Corps Warfighting Publication
MHPCC	Maui High Performance Computing Center

MG	machine gun
MRE	meal-ready-to-eat
MOE	measures of effectiveness
MOP	measures of performance
NATO	North Atlantic Treaty Organization
POL	petroleum, oil, and lubricants
RPG	rocket-propelled grenade
SAW	squad automatic weapon
SE	systems engineering
SEED	Simulation Experiments & Efficient Design
SMSS	Squad Mission Support System
USA	United States Army
USMC	United States Marine Corps
USN	United States Navy

EXECUTIVE SUMMARY

The Expeditionary Energy Office (E2O) of the United States Marine Corps (USMC) strives to find new approaches to conserve energy consumption whether it is in the form of fuel and endurance for the troops or electrical power in the form of batteries for radios. A rifle platoon must have all the necessary resources such as water, batteries, ammunition, food, and special tools at their disposal that adds to the loaded weight of each individual Marine. As physical energy and electrical energy requirements increases, the operational reach of the rifle platoon decreases due to the physical exhaustion, diminishing supplies, and distance travelled that the rifle platoon must overcome.

The purpose of this study is to examine robots that can easily carry the loaded weight currently burdening the Marines. Key objectives are addressed and answered through a systems engineering (SE) approach. From this approach, a baseline integration framework is developed. The study looks at the weight distribution and energy consumption of a rifle platoon with the addition of robotic technology. The cohesive cooperation between robots and the rifle platoon is critical to their combined success.

This thesis research applies simulation models using agent-based model software applications. The rifle platoon is placed in a scouting and patrolling mission based on the Expeditionary Warrior 2012 scenario (EW12). Each case scenario consists of three rifle platoons with the support of a weapons platoon and a range of integrated robots. The assertion is that with the integration of robots into a rifle platoon, the unit will be able to conserve energy while gaining operational reach and maintaining or improving operational combat effectiveness.

The loaded weight on a Marine can be alleviated through incorporating weight bearing robots or pack mules. Literature research shows that Defense Advanced Research Projects Agency (DARPA) and Boston Dynamics' Legged Squad Support System (LS3) robot has a large carrying capacity with an acceptable rate of advance to keep up with a rifle platoon during a scouting and patrolling mission. Simulation model results in this study show that the integration of six LS3 robots is able to provide the rifle platoon a 45.8

percent weight reduction, thereby extending operational reach and improving operational effectiveness. Analysis shows the trade off in these two measures as the number of robots increases or decreases. As the number of robots increases, the platoon's resource consumption decreases while its reach and effectiveness improves.

The framework for incorporating robots into a rifle platoon organization in order to gain operational reach and operational effectiveness is established with this study. The body of this study addresses incorporation of LS3 robots. Graphical and statistical analysis reveals a trade space between six and nine robots per platoon. Six robots are capable of fulfilling the operational needs of the USMC and meeting its energy strategy. From the simulation and analysis, the USMC and E2O can make an informed decision for the integration of robots.

Improvements to the scenario include applying the model to the other robots for similar missions. Simulation time can be adjusted as well as expanding the scenario to include a full Marine expeditionary brigade (MEB), Marine expeditionary force (MEF), or Marine air-ground task force (MAGTF). Conducting an in-depth analysis of alternatives of wheeled or tracked robots should be considered. A cost estimation study or analysis on the financial benefits of using the LS3 robots would allow the USMC to see whether or not it is cost-effective to procure them. Exploring the human factors side to this study would need to focus on the human-robot interaction with LS3 robots. Lastly, the command and control aspect of integrating robots into the rifle platoon's operations is important to the success of the overall mission.

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Secondly, I could not have accomplished the modeling and simulation portion of this research without the exhaustive help of Mary McDonald from the NPS SEED Center. She helped me learn how to use the MANA-V and Pythagoras applications and assisted me in the scenario model planning, development, and execution.

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I. INTRODUCTION

The United States Marine Corps is one of the most capable forces that history has seen on the battlefield. Its motto of "First to Fight" is epitomized in the Marines' ability to project forces anytime and anywhere in the world. Year after year, technology evolves to assist and provide better resources to the Marines. However, the evolution in technology highlights a growing issue, especially for a Marine expeditionary unit (MEU) rifle platoon—an exponential increase in their loaded weight and energy needs. This escalation challenges the Marine Corps to maintain a competitive advantage in operational reach and effectiveness.

The common Marine mission load consists of water, batteries, fuel, ammunition, weapons and other mission essential tools. Marines use a significant amount of physical energy, as well as electrical energy to complete their assigned tasks and missions. They are unable to continue missions for extended periods due to the sheer weight of the load they must carry, ranging from 80 to 100 pounds (Defense Advanced Research Projects Agency [DARPA] 2013).

Energy consumption is a primary concern. Rifle platoons must move constantly from one checkpoint to another in order stay clear of enemy territory. A hostile environment, in addition to constant movement adds to the increased need for physical and electrical energy. Continuous movement equates to a requirement for constant communication with the headquarters company or their main base of operations in order to receive specific tasking and mission orders. The platoon must carry essentials such as water and batteries for radios and other communications equipment. As demand for these resources increase the operational reach and effectiveness of the rifle platoon decreases.

The benefits of robotic technology can be quantified for future military warfare. This research identifies capability shortfalls in which robotics can be applied. Constructed simulations provide a basis to develop an understanding for the cohesive integration of robots in rifle platoon functions.

A. BACKGROUND

Capability gaps still exist in current approaches towards integrating military robots. The focus of this research is the integration of robotics into a Marine rifle platoon and the ensuing net impact on a rifle platoon's operational effectiveness and operational reach. Results from this investigation will show the degree of improvement that robotics may have within the platoon. It provides a basis for inserting robots for defined tasks within the organizational structure of the platoon.

An SE approach defines full integration as multiple elements connecting and combining on a physical and functional level in order to accomplish an activity or task (Blanchard, 2011). Currently, the military uses robots primarily for detection and disposal of improvised explosive devices (IED) and surveillance. However, these robots are considered an addendum to a military unit rather than an integrated asset. These robots are typically remotely controlled and deployed to conduct missions autonomously. This does not meet the definition of integration as outlined by the systems engineering process. The lack of full integration deprives the rifle platoon from the full energy savings that the unit could potentially receive.

This study investigates robots that can literally walk, run, and crawl next to the Marine, as well as respond to verbal commands or visual signals as a human or animal would. This study will research and analyze alternatives that easily can carry the load (weight), provide power, and minimize the overall energy usage of the rifle platoon. State of the market ground robot designs will be discussed and analyzed to select a reasonable robot to incorporate in rifle platoon operations. The study will pay particular attention to the weight distribution and power consumption of a rifle platoon while using robots. By mapping the anticipated savings contributed by these parameters, it equates to lightening the load and reducing energy for the rifle platoon, which in turn extends the platoon's operational reach and also leads to achieving superior operational effectiveness.

This thesis research applies models and simulations with the aid of agent-based modeling: Map Aware Non-Uniform Automata V model (MANA-V) and Pythagoras model. The rifle platoon is placed in conditions representative of the Expeditionary

Warrior 2012 scenario. Equipment and personnel requirements for a rifle platoon are in accordance with an ongoing study by Lieutenant Colonel (Lt. Col) Tom Atkinson, USMC (Atkinson 2003), the Enhanced MAGTF Operations Logistics document (Gelhaus and Robinson 2012), and elements from Captain Charchan's distributed operation loads research (Charchan 2006). Use of an agent-based application can help better understand weight and energy savings by changing the various attributes given to the agents.

B. RESEARCH QUESTIONS

When building the solution for the issue of loaded weight on a USMC soldier and ultimately the entire rifle platoon, there are key questions that arise, including:

1. Is there currently a well-defined human-robot interaction on the battlefield?
2. What specific robot characteristics would be needed to assist the rifle platoon in accomplishing its tasks and mission?
3. To what degree will the incorporation of robotics into a rifle platoon increase its energy efficiency while maintaining its operational effectiveness?
4. What combination of humans and robots is required to maintain effectiveness?

C. OBJECTIVES

Objectives are thought to be end states or desired goals of a project or activity. In this thesis, there are four main desired objectives:

1. Identify the capability shortfalls in the MEU rifle platoon.
2. Research the state of the market robot technology for inclusion in rifle platoon operations.
3. Propose functional and physical architectures for a proof of concept.
4. Establish a framework for analyzing the incorporation of robotics technology in military units such as a rifle platoon.

D. SCOPE

This thesis focuses on the integration of military grade robotics into a USMC rifle platoon, while still maintaining the platoon's overall effectiveness. The two parameters highlighted in this thesis are weight distribution and energy consumption in the form of

fuel and electrical power. Tasks and missions will correspond to a given scenario as outlined by the Expeditionary Warrior 2012 (EW12) report (Marine Corps Warfighting Laboratory, 2012), current USMC doctrine Marine Corps Warfighting Publication [MCWP] *3-11.2 Rifle Squad* and Marine Corps Warfighting Publication *3-11.3 Scouting and Patrolling*. Roughly, the scenario is located off the coast of western Africa, which will include multiple waypoints. The scope of this thesis does not go beyond the USMC organizational structure. As for robotic technology, the study excludes robots that are specifically designed for IED/suspicious package disposal/handling, surveillance, aerial or weaponized robots.

E. LIMITATIONS

Our study recognizes a few limitations. One major limitation is our hands-on experience with the robots in use today. Specifications and documentation from Defense Advanced Research Projects Agency (DARPA) and Boston Dynamics are limited in distribution and require necessary authorizations. Since there will be no field observation of these robots, published reports and articles for information used in integrating robots into the rifle platoon will be relied upon.

One specific robot that will be examined is the Legged Squad Support System (LS3), also known as the Alpha Dog, which is expected to be delivered to the USMC towards the end of 2014 (DARPA, 2013). Other robots that are fully developed and ready for operations could provide benefits to the rifle platoon, but an alternative of analysis is not within the scope of this research.

Command and control is not a focus of this effort. The current configuration of a rifle platoon also poses a problem for integration of robots. There are three squads of 12 personnel within a rifle platoon for a total of 36 personnel. Manning will shift most assuredly with the incorporation of robots. The organizational and operational structures of the USMC as a whole are concrete, but the integration of robotics is focused within the lower ranks where there is more flexibility. With a gradual change approach to the integration of the robots into the military, there is potential for a fully integrated platoon or even a full squad of robots in the future.

F. ASSUMPTIONS

Ideally, the rifle platoon will have no external operational issues in the scenario. For the purposes of this study, a few assumptions are made:

1. The rifle platoon will have all resources and supplies available.
2. Tasking for the rifle platoon will be prioritized by doctrine.
3. The LS3 robots are available for use.
4. The LS3 robots will not require repair and will not be targeted.

G. THESIS STRUCTURE

Chapter II is a literature review for the problem. It provides insight on military robots in use today, as well as the specifications and references published. Background information and previous studies dealing with human-robot interaction (HRI) and modeling robots in the battlefield will be discussed. This section also describes the organization of a USMC rifle platoon and its functions, followed by the USMC energy strategy. Finally, an explanation of agent-based modeling to include applications such as MANA-V and Pythagoras program applications will be described in order to set up the methodology section.

Chapter III contains the methodology of this study. It will describe the SE process approach to this study; the agent-based tools, and the design of experiments that will be used for the data to be collected. An overview of the Expeditionary Warrior 2012 scenario that will be utilized for the simulation portion of the thesis research is outlined in detail. The selected simulation tool will be used for the overall measures of effectiveness of the rifle platoon. Traceability to the objectives and metrics for this study will be outlined as well to provide a better understanding for the subsequent section.

Chapter IV is the analysis and interpretation of the data from the Pythagoras case scenario runs. Microsoft Excel data parsing, graphical displays, analytical and statistical interpretation through the use of statistical software will be presented. It provides an overview of the analyzed data and produces statistical comparisons to provide evidence and results that will assist in answering the research objectives.

Finally, Chapter V contains a summary of findings and results, the conclusions from the analysis and interpretation of results, recommendations to the problem, and follow-on work that can be applied to this research topic.

H. BENEFITS OF THE STUDY

Achieving the objectives of identifying the capability gaps and researching the state of the market technology benefits this research. Consecutively, proposing functional and physical architectures and establishing a framework for the incorporation of robotics into a rifle platoon, benefits the main stakeholders to the troops on the ground.

The USMC Expeditionary Energy Office as well as the USMC higher authorities will benefit in several ways from this research. The E2O is very interested in finding ways to conserve fuel and power energy across their branch of service. It is essential that energy use and consumption is kept at a minimum while maximizing the platoon's performance and capabilities.

The USMC is also interested in finding ways to make its units more efficient as well as effective or able to function successfully without disadvantages, such as waiting for vehicles to be fueled, batteries to be charged, and Marines to overcome fatigue from the loads they carry. As a by-product of this research, other branches of the armed forces can take this study and apply it to their own service, research or other potential developments in robotics.

Operational commands, such as the Joint Special Operations Command, can utilize this study to form better organizational units that are capable of extending their operational reach. The headquarters commands can apply this foundational framework and architectures to the other service branches and gradually create a unified approach to joint efforts around the world.

The science and technology communities as well as research and development companies also will be invested and interested in this study since it will directly impact their way of business. It will keep their employees and engineers designing and creating even better robots for the future.

Lastly, the troops who will be working with this robotic technology will gain new insights and lessons learned from this study. They can adapt and reorganize within the platoon itself to work cohesively to accomplish the mission.

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II. LITERATURE REVIEW

A. INTRODUCTION

This chapter discusses the background information necessary for understanding the key elements of this study. It also presents previous research conducted and/or literature published on the subject matter. The first section discusses the current status of military robots and their interactions with humans, followed by the current modeling and simulation experiments and studies that have been conducted to show that robots are the future of modern warfare. The USMC rifle platoon configuration itself and background information about the current energy strategy from the USMC perspective is then presented. A brief discussion of agent-based modeling and the basic design of experiments in MANA-V and Pythagoras programs are provided to get a better understanding of the purpose of this study.

B. MILITARY ROBOTS IN THE TWENTY-FIRST CENTURY

Since Nicola Tesla built a remote controlled boat in 1898, robotics has been an ever-growing technology (“History of Military Robots” 2013). Now in the twenty-first century, robots are everywhere in the workplace, in the home, and even in the military. The human-robot interaction is a difficult challenge, especially in the military. When hostile threats and dangerous missions occur, ground units need to be prepared for combat. Currently, robots in the military come in a variety of types, sizes, and shapes with different capabilities and specifications. Most military robots used today are “teleoperations of unmanned ground vehicles [UGVs]” for search and rescue and IED disposal (Evans 2010). The military also uses robots such as unmanned aerial vehicles (UAVs) for surveillance and reconnaissance. More recently, engineers and designers have created robots to act as pack mules or load bearing robots to provide advanced tasks, logistics supply, and battlefield casualty evacuation (Evans 2010).

IED robots serve a great purpose to the military in the sense that they keep our troops safe by freeing them from very dangerous tasks such as inspecting and dismantling explosive devices and bombs. Rather than send a human being in, the robot takes on that

role and the human can remain a safe distance away. These robots ensure safekeeping of the human operator with no injuries or death, and only the robot itself may sustain damage. Examples of these types of robots include the iRobot PackBot Fas Tac system and TALON created by Foster-Miller (Hutchins et al. 2010).

Surveillance and reconnaissance military robots are the hidden “eyes in the skies” that provide critical imagery and information to units on the ground. These UAVs take pictures and record footage of certain sites that the MAGTF, the MEF, the MEB or the MEU wishes to know more about. Gathering intelligence in this way, without having to risk human lives by placing them into hostile territory, is critical to battle. Examples of these UAVs can vastly range in length, height, and weight. Among the largest are the General Atomics MQ-1 Predator and the Northrop Grumman RQ-4 Global Hawk; while among the smaller UAVs is the joint design of DARPA and AeroVironment’s Wasp Micro Air Vehicle (MAV).

Unmanned motorized vehicles have also become popular in the past decade. Again, without risking a human life, wheeled and track robots can traverse hostile territory and still support the units. These particular vehicles, such as the Squad Mission Support System (SMSS) built by Lockheed Martin, have even been deployed to Afghanistan and evaluated with the ground troops (Lockheed Martin 2013). While its cargo capacity and speed are extremely desirable, this four-wheeled unmanned vehicle design is not mobile like other smaller robotic systems that can walk, trot, and run with the ground troops.

Even though these robots assist and aid the troops in disposing of dangerous packages, gathering intelligence, and traversing hostile territory, none of them work side-by-side with their human operators. The collaboration or teamwork of the human-robot interaction is critical, especially on patrol and scouting operations. This is where moderate sized load-bearing robots come into action. These robots are designed to walk, trot, run, and crawl with the soldier as if they were another asset (Marine) to the unit. Not only do they provide assistance with carrying the weight of equipment, water, food, ammunition, tools, and medical supplies, but they also aim to provide the platoon with an

energy source or re-charging station. Examples of these robots that are in development today include the LS3 and Maximum Mobility and Manipulation (M3) systems also known as the BigDog, the WildCat, and the Alpha Dog.

As previously stated, to alleviate the issue of weight, robots are being developed by companies like DARPA and Boston Dynamics along with assistance from facilities such as Foster-Miller, the NASA Jet Propulsion Laboratory, and the Harvard University Concord Field Station. The BigDog is a DARPA and Boston Dynamics original design and the precursor to the Alpha Dog; both designs are under the LS3 program. Designed in 2005, this original version of a four-legged robot came to be known as BigDog, Figure 1. BigDog stands 3 ft. tall by 3 ft. wide and weighs about 240 pounds (Raibert et al. 2008). It was built for its agility over 35 degree inclines and rough terrain such as rocks, mud, ice, and snow. The robot has the capability to carry 340 pounds, significant help to troops (Boston Dynamics 2013a). It was designed to be similar to that of a small mule and is even capable of throwing cement cinder blocks (Boston Dynamics 2013a).

Figure 1. The LS3 BigDog in Action built by DARPA and Boston Dynamics (from Knowles, 2013)

Another robot under the M3 development program at DARPA is the Cheetah robot. The Cheetah robot looks nearly like the actual animal with a sleek design that easily runs up to 28-29 mph, but that is when it was tethered to cables and running on a treadmill in a laboratory (Anthony 2013; DARPA 2013). Now, DARPA has developed the WildCat that is built for high speed and small amount of weight, but it is untethered and free-standing in comparison to its predecessor the Cheetah. DARPA is still conducting outdoor testing on the WildCat, but this free-running version of the Cheetah can run up to 16 mph and is expected to eventually gain speed up to 50 mph and still be capable to do so over different types of terrain (Anthony 2013). While it can only carry a little right now, it will eventually carry heavier loads. The key factor for this robot is its agility, speed and ability to get the job done fast by transiting from point A to point B rapidly over fairly flat terrain with the potential to run over rough terrain. However, the M3's main purpose is to create more fluid and flexible robots that are currently being designed and built today, but not necessarily designed strictly for the battlefield and human-robot interaction (Boston Dynamics 2013b).

Figure 2. The M3 WildCat built by DARPA (from Anthony, 2013)

Originally, Big Dog was a tethered design and in the late 2000s, DARPA and Boston Dynamics wanted to take LS3 Big Dog to new extremes—a free-standing design. This led to the creation of the LS3 Alpha Dog, which is the biggest in the DARPA robot family. It is a four-legged robotic system that is capable of carrying up to 400 pounds while maintaining its stability on easy to rough terrain, as well as functioning in hot and cold environments. The LS3 Alpha Dog can operate for 20 miles or more than 30 kilometers and travel at least 24 hours (Boston Dynamics 2013a; DARPA 2008; Williams 2013). The robot itself weighs approximately 850 pounds and requires nine gallons of fuel for a 24-hour mission (Christopher Orlowski, pers comm. April 15, 2014; DARPA 2008). It is intended to function much like a pack mule and/or like a trained animal (Cronk 2012). Development of the Alpha Dog began in 2009 and the first operational prototype was tested in 2012. The Alpha Dog will function autonomously much like a pack mule for the squad or platoon. The mission of DARPA and Boston Dynamics is to "demonstrate that a highly mobile, semi-autonomous legged robot [that] can carry a squad's load, follow squad members through rugged terrain and interact with troops in a natural way, similar to a trained animal and its handler" (DARPA 2013). This robot was designed specifically to carry a heavy amount of loaded weight unlike its counterpart the WildCat, which was built for rapid movement support. Currently, there are two prototypes being field tested (Figure 3) and the program is in Phase II, Appendix A.

Figure 3. Two LS3 Alpha Dogs in a Field Exercise (from DARPA, 2013)

Specifics on the LS3 robot and its program are provided in Table 1 and in Appendix A and serve as the requirements that DARPA and Boston Dynamics used in the development of this robot. DARPA highlights speed, distance, time, noise, and power as critical to this system. Identifying their limitations and/ or capabilities with these metrics in mind will provide information for the integration of these robots into a rifle platoon for this study.

Table 1. LS3 Alpha Dog Mission Profile (from DARPA 2008)

Item	Description	Speed	Distance	Time	Noise	Auxiliary Power
1	Moderate Hiking Trail	3 mi/hr.	9.0 mi	3.00 hr.	70dB	0.75 hp
2	Idle - squatted	0 mi/hr.	0.0 mi	0.50 hr.	60dB	0.75 hp
3	Easy Road Trail	5 mi/hr.	5.0 mi	1.00 hr.	70dB	0.75 hp
4	Idle – squatted	0 mi/hr.	0.0 mi	0.50 hr.	60dB	0.75 hp
5	Complex hiking trail	1 mi/hr.	1.0 mi	1.00 hr.	70dB	0.75 hp
6	Easy Road Trail	10 mi/hr.	0.5 mi	0.05 hr.	70dB	0 hp
7	Idle – squatted	0 mi/hr.	0.0 mi	0.50 hr.	60dB	0.75 hp
8	Moderate Hiking Trail	3 mi/hr.	3.0 mi	1.00 hr.	70 dB	0.75 hp
9	Moderate Hiking Trail	3 mi/hr.	0.5 mi	0.16 hr	40 dB	0.75 hp
10	Easy Road Trail	10 mi/hr	0.5 mi	0.05 hr	70 dB	0 hp
11	Maneuver at objective	1 mi/hr.	0.5 mi	0.50 hr.	70 dB	0.75 hp
12	Standby - squatted	0 mi/hr	0.0 mi	15.74 hr	40-60dB mixed	0.75 hp
	TOTALS		**20.0 mi**	**24.0 hr.**		

DARPA and Boston Dynamics are the leaders in this arena. They have a family of robots to include a human-like robot named Atlas, a feline robot called WildCat, and a canine robot called Alpha Dog. They do not plan to use them all in a squad where the human-like robot fires weapons; the dog is used as a pack mule and the cat is the highly maneuverable support system (Anthony 2013).

It is evident that in today's world technology has grown and developments in digitization have made it possible not only to include visual aides to the human operators, but to provide audio cues as well, making the robots interact on a more human-like level (Haas and van Erp 2010). The HRI can be depicted with four key elements of robotic

technology, a communication network, controls and displays, and the human operator (Allender 2010). The challenge now lies in bringing those elements to function cohesively as a unit, with the intention to lighten the load for the soldiers in order for them to endure longer missions and extend their operational reach or extend their range within the area of operation. With a tool and resource like this, the soldiers can become more effective fighters since the loaded weight is lifted.

C. MODELING ROBOTS IN THE BATTLEFIELD

Human-robot interaction experiments are a relatively new form of study in the past decade. While it is true that there have been multiple studies about the human-computer interaction (HCI), not many have ventured into how the human and robot interact together and even fewer studies utilizing modeling and simulation as a means to express and analyze those interactions. Current HRI studies pose major challenges not found in HCI studies to include functionality and compatibility with robots and humans working side-by-side as opposed to humans interfacing or utilizing the computer system as a tool (Feil-seifer and Mataric 2013). Robot wars and battles have become popular in the classroom, in higher level education establishments, and companies such as Intelligent Automation, Inc. that use modeling and simulation to assist others, for example the U.S. Navy, with medical evacuations in the battlefield, but none have truly used modeling and simulation to determine whether or not the human can function cohesively with a man-made machine in the battlefield (Intelligent Automation, Inc. 2013; Jones 1997).

In 1987, the U.S. Army and the Department of Defense (DOD) conducted a simulation to model robotic vehicles on the battlefield. This marked the beginning of using models and robots in conjunction with one another for research purposes (Small Business Innovation Research 2013). The U.S. Army continued its research again in 2002, with a study entitled "Representing Ground Robotic Systems in the Battlefield," which provided the framework for modeling and simulation in the battlefield to include external and internal command and control, communications, navigation, and payload. It examined the DEMO III robotic system using the OneSAF simulation program and

concluded that as the scale of these combat models increases, development of more abstract models are required (Fields 2002). Finally, in 2011, a study was written about using "Robotic Operator Managers" for the battlefield scenario. In this case, the model serves as the dynamic decision maker and instance-based learner. The model itself predicts the threats and then decides where the squad or platoon should maneuver (Dutt et al. 2011). While both of these studies used robotics within their experiments as well as creating complex models and simulations, none of the studies leveraged that information in order to reduce energy consumption as the USMC desires its service, especially the ground units, to accomplish.

D. A USMC RIFLE PLATOON

The USMC rifle platoon is a critical component of a MEU. The USMC has used basically the same organizational structure since its inception in 1775, with added necessities such as weapons companies and artillery units to adjust to the changing times and upgrades to modern warfare. A typical MEU can sustain itself up to 15 days and is commanded by a colonel. The MEU is broken into a ground combat element (GCE), including the infantry, battalion landing team (BLT) with company landing teams (CLT), an aviation combat element (ACE) or component squadron consisting of helicopters and aircraft, a logistics combat element also known as the combat logistics battalion (CLB) and a command element. Within the ground combat element, led by a lieutenant colonel, elements such as the infantry company, rifle/weapons company, artillery battery, tank platoon, recon platoon, and engineering platoon reside. The rifle/weapons company consists of a company headquarters with a weapons platoon and three rifle platoons (USMC 2002). The smallest element of the rifle platoon is the fire team, which is made up of four soldiers. Three fire teams make up a squad, led by the squad leader, who is typically a 2nd lieutenant. Three squads for a total of 36 soldiers, make up an entire platoon. Within the rifle platoon headquarters there is a commander, typically a 1st lieutenant or a captain, a platoon sergeant, a platoon guide, and platoon messengers (USMC 1978). The rifle platoon's mission is simple, "locate, close with, and destroy the enemy, by fire and maneuver, or repel the enemy assault by fire and close combat" (USMC 1978). Perspectives from actual infantry officers and their opinions about the

organization, structure, missions, and tasks also provide insight into the workings of a USMC rifle platoon, Appendix B. The basic organization of the rifle platoon is seen in Figures 4 and 5.

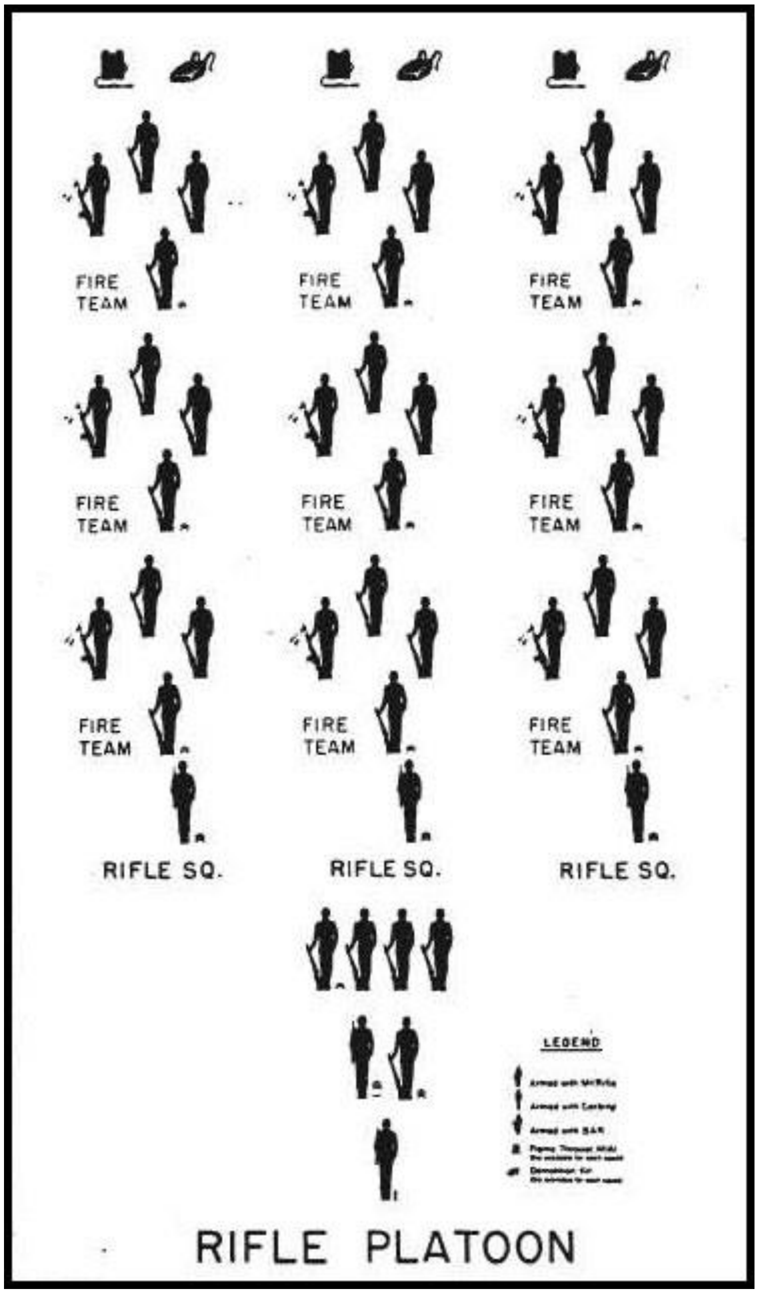

Figure 4. Basic Rifle Platoon Organization (from Hyper War, 1944)

In Iraq and Afghanistan the rifle platoon's organization stayed consistent, but advanced technology and weapons are also included to combat the enemy forces. Load outs have become heavier and the rifle platoon is still required to achieve the mission while carrying the weighted burden.

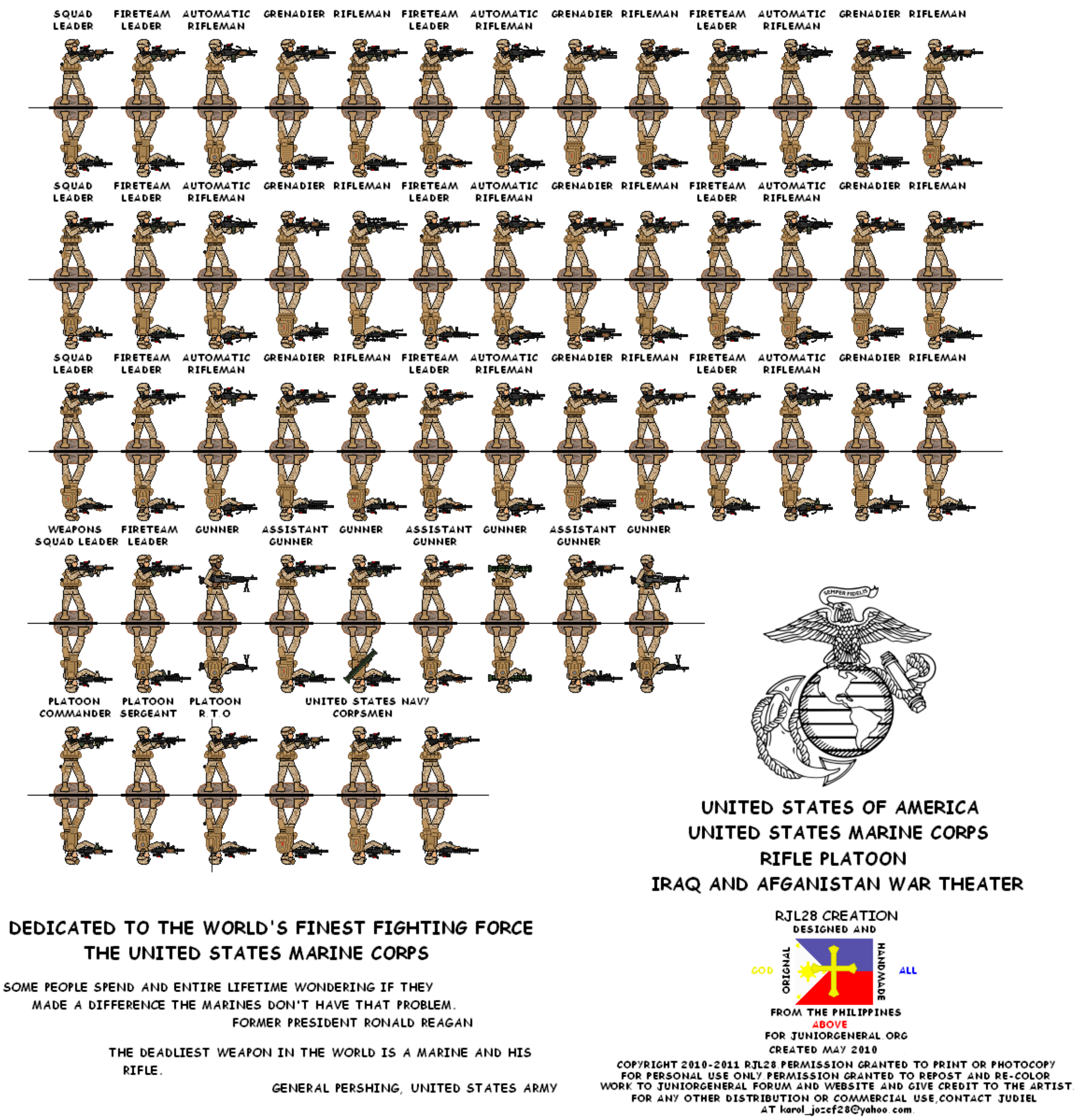

Figure 5. Iraq and Afghanistan USMC Rifle Platoon (from Junior General, 2013)

A typical load out for the MEU ground element includes M1A1 tanks, assault amphibious vehicles (AAVs), light armored vehicles (LAVs), 155mm Howitzers, 81mm mortars, 62mm mortars, Mk-19 40mm grenade launchers, BGM-71 tube-launched, optically-tracked, wire-guided (TOW) launchers, FGM-148 Javelins, and .50 caliber machine guns. The rifle platoon primarily uses M240 machine guns, M249 light machine guns or squad automatic weapons (SAW), M203 grenade launchers, M27 infantry automatic rifles, M4/M16A rifles, and 9mm pistols. The platoon also has the capability to carry the 81mm mortars, 62mm mortars and the EFSS M327 120mm towed rifled mortar weapon if necessary, depending on the particular mission (Joint Military Professional Education 2013; Sprincin 2007).

Captain Charchan's distributed load in accordance with MAGTF operational loads explains that in order to have mission success, the platoon should include machine guns for anti-armor and anti-tank fires as well as external and intra-squad communications (2006). He also names automatic rifles and pistols for individual protection, night vision, extra ammunition, as well as hydration equipment (Charchan 2006). This study will include water, batteries, and extra ammunition, food and other supplies as the main resources for the platoons.

E. THE USMC'S ENERGY STRATEGY

With growing technology and energy consumption all over the world, the military, especially the USMC, has looked at finding ways and strategies to consume less energy and yet remain effective as a deterrent, as a humanitarian assistance force, and as a power presence. The USMC wants to continue its present war fighting efforts, yet do so without leaving such a large carbon footprint. The USMC wishes to maximize the efficiency and operational reach of its troops, and decrease their energy usage.

In 2009, the Commandant of the Marine Corps made energy conservation a top priority and declared that the "current and future operating environment requires an expeditionary mindset geared toward increased efficiency and reduced consumption." This in turn definitely makes the troops and units "lighter and faster." The USMC strives to develop "solutions to reduce energy demand in our platforms and systems" while still

"increase[ing] self-sufficiency" as well as "reduc[ing] [the] expeditionary foot print on the battlefield." The Expeditionary Energy, Water and Waste (E2W2) program plans to support the commandant and his vision (Marine Requirements Oversight Council 2011).

F. AGENT-BASED MODELING

Over the past few decades, the concept of agent-based modeling has come into the picture, along with the rapid growth of technology in computers and computer applications and resources. Some applications are quite complex, but others are simpler. These applications range from collecting data to observing financial market behaviors to observing counter terrorism and other military operations in a simulation. The Von Neumann Model, developed in 1946, consisted of a theoretical machine or computer architecture that replicated itself based on a prescribed series of processes that proved to be the beginnings of modeling and simulation as known today (Cragon 2000). Modeling and simulation soon became popular in the 1990s. There are simple to complex agent-based modeling tools in the marketplace today that serve a great purpose supporting the military's research and development as well as analysis of the modern warfare battlefield. Two particular applications that are widely used and will be utilized in this study include MANA-V and Pythagoras.

The *Map Aware Non-Uniform Automata—Vector* (MANA-V) is a simple agent-based resource tool. It was developed in 2000 by Defence Technology Agency (DTA) for use in military operations and analysis studies (McIntosh 2009). The updated model uses a vector-based scheme, meaning that the user can see larger battlefield regions, the battlefield distances and agent speeds can be defined directly in terms of real world units, and sensor and weapons characteristics can also be specified directly using real world units. MANA-V uses a simple blue force vs. red force idea and places the forces in a battlefield for operational analysis. The application provides a way for the user to see the lessons learned in certain situations.

Another agent-based application is Pythagoras, developed by Northrop Grumman as a non-traditional model to support the growth and refinement of Project Albert (Henscheid 2010). It is a more complex version of the MANA-V agent-based model

application and originally started out as a method by which simple scenarios could be run on multiple platforms and be analyzed via data farming techniques on the Gilgamesh platform located at the Maui High Performance Computing Center (MHPCC). While more traditional combat modeling and simulation concentrates on the physical aspects of combat, Pythagoras uses parameters such as rates of movement, rates of fire, lethality, the effect of weather, and terrain as mathematical representations. Since the combat environment involves the physical world to include human factors and leadership or influences that the soldier might encounter, the application strives to emulate these attributes into the program. Pythagoras offers a unique set of capabilities in the area of agent-based simulations such as incorporating soft rules to distinguish unique agents, desires to motivate agents to move and shoot the enemy, the concept of sidedness or affiliation to different agents represented by color value, behavior changing events and actions (triggers), generic attributes that can vary or be used to control and influence other agents, generic resources that can be replenished or depleted, and traditional weapons, sensors, and terrain (Grumman 2008; Henscheid 2010).

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III. METHODOLOGY

A. OVERVIEW

This chapter will discuss the methodology for this study. It will describe the systems engineering approach to include modeling and simulation tools considered and ultimately used, as well as the traceability of capabilities, functions, and measures of effectiveness. The expeditionary scenario in accordance with Expeditionary Warrior 2012, the design of experiments, and the baseline and subsequent case models applied to the scenario will also be described in detail.

The purpose of this research is to discover how the integration of robots can lighten the load of a USMC rifle platoon thereby extending operational and increasing its operational effectiveness. To achieve the research objectives, a systematic approach is outlined in the following flow diagram, Figure 6.

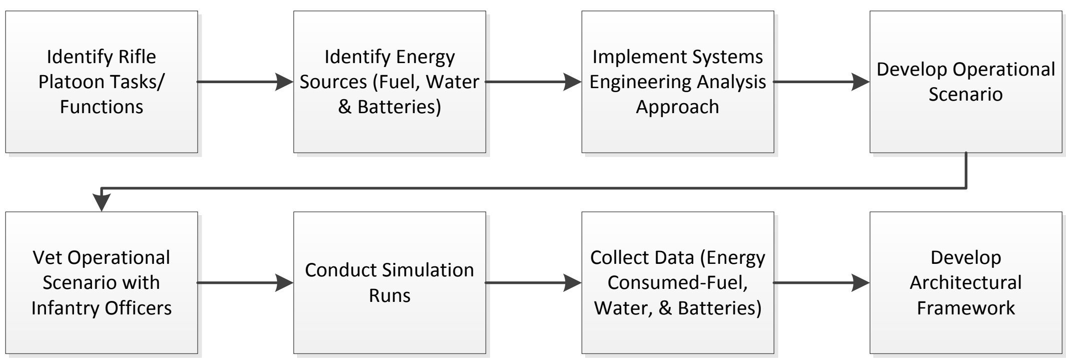

Figure 6. Diagram of the Systematic Approach to Meet Objectives

B. SIMULATION TOOLS

Agent-based models are relatively easy to use and manipulate. Since the scenario appears to be simple in nature, MANA-V is an obvious consideration. Through its availability and compatibility within the Naval Postgraduate School and the Simulation Experiments & Efficient Design (SEED) Center, MANA-V is a great option. MANA-V provides capabilities that can be tailored to reflect the factors present in the scenario above. As the scenario began to take shape, it became evident that more than one

parameter (resource) needs to be accounted for and observed. MANA-V could only accommodate one consumable, rather than the three or more consumables that this study aims to observe. Resource consumption, distance travelled, and combat effectiveness need to be monitored and extracted from the model. With that in mind, MANA-V is proved to be an unacceptable option for this simulation effort.

Pythagoras is another agent-based model similar to MANA-V, but includes more complex and advanced features and attributes that fulfill the requirements needed for this study as explained in the previous chapter. The user can manipulate more of the scenario and add more attributes to the agents, such as adding more troops, including more weapons, and adding different sensors needed for the scenario. Pythagoras also allows for more than one consumable to be tracked, which is desirable for this study. It also allows for "sidedness" or more complex behavioral attributes to be implemented into either the human agent or the robotic agent.

With Pythagoras as the selected application for this study, three case scenarios based on the original scenario are created. First, is a baseline case that only uses troops or human agents; the second is a combination of human agents and robotic agents; the third case is the maximum number of robotic agents necessary for the platoon. Each case scenario will run for a total number of 12,960 time steps per simulation run, which is equivalent to 72 hours. There will be 50 runs per each case scenario.

C. TRACEABILITY TO OBJECTIVES

Traceability is critical to understanding how capabilities, objectives, and measures are linked or fit together. Once the scenario outputs the parameters and data needed for analysis, the statistical information gleaned will provide the basis for this framework. The SE approach shows that platoon tasks and functions can be mapped to the overarching capabilities or desired outcomes of the platoon(s) and robot(s), which will impact the energy consumption overall, Table 2.

Table 2. Capabilities to Functions Mapping

Rifle Platoon Mapping		
Desired Outcome	Function	Tasks
Conduct Scout/Patrol	Traverse Western Africa AO	Maneuver on flat to rough terrain and environments
	Conduct offensive and defensive maneuvers	Engage enemy and defend platoon
	Communicate with higher authority	Send and receive radio calls
Conserve Energy	Reduce carbon footprint	Bring minimal amount of equipment
	Use less water, batteries, POL	Reduce amounts and utilize robots or convoys
	Reduce Fatigue	Lift weighted load from platoon
Integrate Robots	Decrease weighted load	Carry excess platoon loads (above 100 lbs.)
	Recharge Batteries (Cronk 2012)	Equip platoon with charging station
Extend Operational Reach/Effectiveness	Increase troop alertness/readiness	Maximize sleep / Minimize fatigue
	Increase endurance of troops	Decrease weighted load

Along with capabilities and functions and as part of the SE approach there needs to be a way to show the associated measures of effectiveness and how the accomplishment of the objectives will be met (Stevens 1979). These measures are then mapped with the associated measure of performance, which will be extrapolated from the scenario as tangible data and their technical parameter that is manipulated through the use of the resources and attributes given to the agents within the scenario, Table 3.

Table 3. Measures of Effectiveness Mapping

Rifle Platoon's MOEs		
Measure of Effectiveness	Measure of Performance	Technical Parameter Measure
Complete Mission-Secure Dakar	Maneuverability through terrain (normal, veg, urban)	Distance Traveled
	Engagement of enemy when necessary	Number Killed, Amount of weapons used
Conserve Energy	Reduction of carbon footprint	Amount of fuel, water, and batteries
	Less usage of water and POL	Amount of fuel, water, and batteries
Integrate Robots	Reduction of weighted load	LS3 cargo capacity
	Capability to recharge batteries (Cronk 2012)	LS3 power supply
Extend Operational Reach/Effectiveness	Ability to increase of troop alertness/readiness	Rest periods, resources consumed
	Ability to increase endurance of troops	Rest periods, resources consumed

Measures of effectiveness (MOE) and measures of performance (MOP) are also prioritized; this leads to a better way of accomplishing the research objectives of integrating the robots into a strong framework. The MOEs/MOPs listed above have been prioritized accordingly:

1. Extend Operational Reach (MOE)
2. Increase Operational Effectiveness (MOE)
3. Conserve Energy (MOP)
4. Maneuver through Terrain/Complete Mission (MOP)

D. EXPEDITIONARY SCENARIO

The Expeditionary Warrior 2012 is a part of the USMC Title 10 war game. The game is set in a fictional scenario in 2024 Africa. It is intended to serve as a means of identifying potential gaps and opportunities for enabling joint force access and entry against adversaries in an anti-access and area-denial environment. The war game explores operational challenges, potential shortfalls, and naval integration opportunities for the Joint Operational Access Concept (JOAC), the Navy and Air Force's Air-Sea Battle Concept, and conceptual initiatives from the Marine Corps' Amphibious Capabilities Working Group. EW12 consists of three moves containing a total of five vignettes also known as "what-if" scenarios. Across these three moves, these vignettes focused the attention of the participants on research questions linked to the sub-objectives and focus areas (Marine Corps Warfighting Laboratory 2012).

The scenario for this study is a subset of the EW12 scenario and is loosely based on Phase III, Vignette 5 of the final report. The area of operation for this study is located off the western coast of Africa, near Dakar. In this phase, the MEU has already conducted an amphibious assault at Objective 5. From the main base headquarters on the established beachhead, the rifle platoons and weapons platoons will continue up the coast in order to capture and secure the city of Dakar, Figure 7. The platoon will navigate its way through terrain similar to the current terrain in Africa, to include dirt, desert, light forest and vegetation, and an urban area. There will be multiple checkpoints that the platoons must arrive at and report their status. The platoon will start from the amphibious landing site (main base) with all the necessary equipment and gear to include fuel, water, batteries, ammunition, food, and other supplies. The rifle platoon will transit and patrol the area to the north of the landing site. The last stage of the journey will be securing the city of Dakar, which is the urban terrain the platoons must traverse.

Figure 7. Scenario in Dakar with Checkpoints

Figure 7 shows the starting point at the amphibious landing spot, two waypoints and the final objective in downtown Dakar. Each waypoint has an (x,y) coordinate associated with it. All waypoints, distances, and markers in the Pythagoras model are in pixels. These conversions are summarized in Table 4.

Table 4. Pythagoras Playboard Summary

Pythagoras Playboard		
Real X (km)		Real Y (km)
	34	22
Pixels (X)		Pixels (Y)
	1700	1100
	meters per pixel	20
	Total Sim Time (hrs.)	72
	Time step (sec)	20
	Num Time steps	12960
	Time Steps per minute	3
	Time Steps in an Hour	180
	Time Steps in a Day	4320

In Pythagoras, Figure 7 appears to be clustered, so a much simpler background is embedded for clarity and better visualization of troop mobility, Figure 8. This map graphic is imbedded within the Pythagoras database for simulation use.

Figure 8. Clean Version of Dakar Background (from National Geographic, 2013)

Scheme of maneuver:

Mission: Conduct scouting and patrol on and near the towns of Rufisque, Pikine and Dakar. Secure city of Dakar from Western African enemy hostile militia/guerilla groups (infantry, militia, and mortar).

Duration of Mission: Three days (approx. 72 hrs.) with pre/post mission days not included in the simulation; total distance of mission is approximately 30 km or 10 km from waypoint to waypoint.

Day One (Pre-Mission Day-12 hrs.): MEU arrives at Blue Beach Z to set up command and control as well as base camp from amphibious landing site (initial position). Organization and briefing on the situation given to platoons. Pack all equipment and supplies for platoons and LS3 Alpha Dogs to include ammunition, weapons, radios, batteries, water, rations, and diesel for the robots where each robot can

carry its own diesel supply of nine gallons, which is equivalent to 75 pounds, according to Major Christopher Orlowski, USA, Program Manager for the LS3.

Day Two (Mission-24 hrs.): Three platoons set out on patrol towards Rufisque and Waypoint 1, following close to the main road N1. Encounter vegetation terrain and Red Mortar hostiles. Spend maximum of three to five hours on station and assess damage/casualties/equipment loss, and LS3 Alpha Dog status.

Day Three (Mission-24 hrs.): Once out of danger, the platoons set out again on scouting and patrolling towards Pikine and Waypoint 3. Encounter more vegetation terrain, plus water in the form of a lake and continue on N1 road towards Dakar. Encounter more enemy troops (Red Militia). Engage enemy for maximum of three to five hours on station for combat. Assess damage/casualties/equipment loss and LS3 Alpha Dog as well as platoon status.

Day Four (Mission-24 hrs.): After Waypoint 3, platoons set out on final leg of mission towards Dakar. They continue scouting and patrolling. The mortar sections take a secure position outside the city of Dakar. The platoons encounter urban terrain and Red Infantry hostiles. Again, since this is the last leg, they spend maximum of three to five hours on station in order to secure Dakar at Waypoint 5. Finally, they assess damage/casualties/equipment loss, LS3 Alpha Dog status, and platoon status.

Day Five (Post-Mission Day-12 hrs.): Conduct debriefing and report to higher authority. Assess personnel casualties, property loss, equipment and supplies shortage. If required, the platoons will request more supplies, but a convoy is needed.

E. DESIGN OF EXPERIMENTS

By using modeling and simulation and design of experiments (DOE) to explore robotics integration, the pitfalls or gaps become visible and more readily identified. Ultimately, the idea behind this study is simply outlined by the flow diagram in **Error! eference source not found.**9. By integrating robotics, the rifle platoon's individual loaded weight will be reduced. We expect that energy usage will also be reduced, thereby extending the rifle platoon's operational reach, as well as its operational effectiveness.

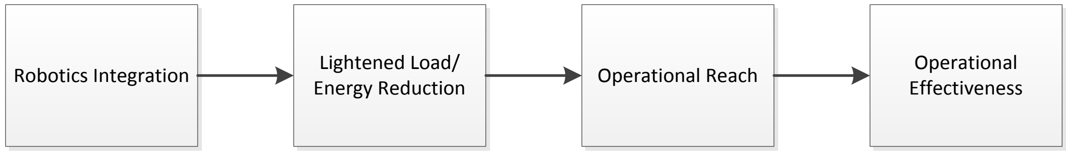

Figure 9. Flow Block Diagram of DOE Outcome

A DOE is a systematic method that explores the variation and change of a subject of interest. DOEs are typically used for natural and social sciences as well as engineering. The SE process marries well with simulation DOEs. The analyst has full control of all aspects of the experiment. The DOEs enable the analyst to examine the different effects of the process, intervention or treatment of certain parameters within the experiment (Stevens 1979).

From a statistical viewpoint, these types of experiments are controlled. Formally planned experimentation is often used in evaluating physical objects (soldiers and robots), structures (organization of the rifle platoon), and materials (consumables such as fuel, water, and batteries). In Pythagoras, physical objects, structures, and materials can be manipulated and observed with ease. Each tab under the Pythagoras interface has different inputs for terrain properties, weapons, sensors, communications, and behaviors. Highlighted below are a few elements that are critical to the model:

1. The Agents

An agent in this scenario is a single unit that can move as one and behave in a similar manner. One agent is equivalent to four troops or a fire team. Table 5 shows the numbers of agents used within the Pythagoras application and their equivalent count in a Marine unit.

Table 5. Agents and Equivalent Troop Count

Number of Agents	Actual Troops
1	4
3	12
9	36
10	40
20	80

a. *Blue Agents*

The USMC company, made up of three platoon agents, is the main body that will be examined for energy consumption. For support and protection, a weapons platoon made up of three machine gun (MG) sections and three mortar sections will provide fire support for the platoons as they traverse the terrain. They will possess weapons such as M240G machine guns and 60mm mortars respectively.

b. *Red Agents*

These agents are the enemy hostiles or guerilla and militia of Western Africa and are grouped into sections of infantry, militia, and mortars. There are 25 agents within each of the infantry and militia groups and 10 agents within the red mortar group for a total force structure of 60 agents. These agents are not as skilled as the Blue Force, but do have some similar capabilities and features such as sensors and communications, with a variety of weapons to include AK-47s and rocket-propelled grenades (RPGs).

c. *Robot Agents*

These agents are a part of the Blue Force. They supply the platoon agents with resources. They may also allow the blue agents to offload their weight onto the robot. The robot agents have an initial load of resources for the entire scenario.

2. The Resources

There are four resources that are considered in this scenario—X, Y, and Z as well as fuel. Fuel represents the endurance of all Blue Force agents and diesel for the robot agents. These two components are aggregated into one value in Pythagoras. Resource X represents water for the agents in pounds converted from liters. Resource Y represents battery weight in pounds. Finally, resource Z represents other supplies such as food, in the form of meals-ready-to-eat (MREs), medical kits, special tools, petroleum, oil, and lubricants (POL) or extra diesel gasoline for the robots.

Figure 10 displays the Pythagoras interface resources tab or what the robot can supply to the blue platoon, MG, and mortar agents. The robot agents are given a predetermined standoff distance from the other agents of 10 pixels or 200 meters, but they are able to re-supply the agents almost instantaneously. Load outs for the robots vary with each case, Appendix E. The robot agents are the only agents that are able to resupply other agents.

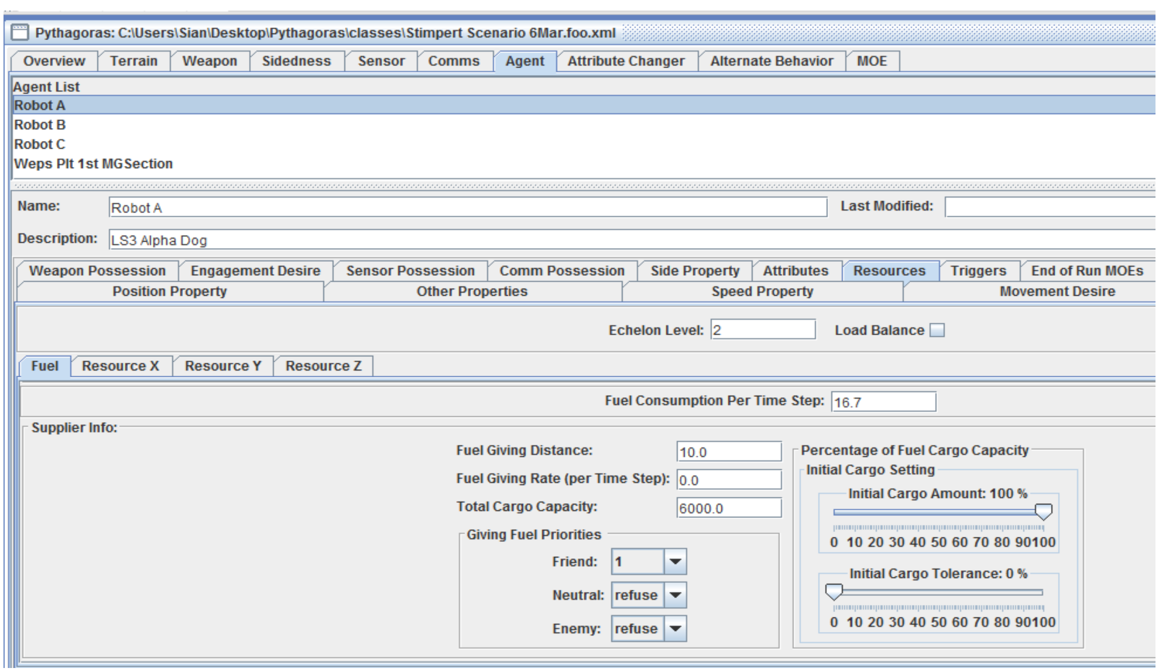

Figure 10. Robot Agent Supplier Information for Fuel Resource

3. Their Attributes/Behaviors

a. Patrol Behavior

The blue force's main behavior is to patrol. The agents will proceed to the waypoints outlined at a certain movement speed depending on the terrain (land, vegetation or urban). The speed property of most agents is set to one (1) meaning one pixel (20 m) per time step. See Appendix C for actual real world movement speeds.

b. Engage Enemy

Should the enemy be within a particular distance, the Blue force agents will break from their patrol behavior and proceed to attack and defend against the enemy troops. The enemy must be within weapons maximum ranges or within line of sight (LOS) for the Blue force to attack. In the scenarios, the agents must be within a range of 20 to 30 pixels for engagement to occur.

c. Rest Behavior

This behavior comes into play once the agents have reached a particular waypoint. They will report the status of resources and reorganize themselves before continuing on to the next waypoint. The robot agents can resupply the blue agents at this point as well. In this behavior the agent's speed property is reduced to zero and the agents will wait a period of time steps before continuing onto the next waypoint, Table 6. Since this behavior is similar to sleep it will allow the agents to regain their alertness and combat readiness.

d. Fatigued State

In this behavior the agents have become overburdened either by lack of resources or by engagement with the enemy. They have reached critical limits for the mission to continue. Agents have an increased vulnerability and decreased marksmanship in this behavior. Table 6 explains the real world times and Pythagoras time steps associated with the rest and fatigued behaviors.

Table 6. Rest Periods and Durations (in Time steps)

State Durations and Triggers			
Rest 1	Rest 2	rest dur (hrs.)	8
2160	6480	rest dur (ts)	1440
		fatigue dur (min)	20
		fatigue dur (ts)	60

e. Resource Out Behaviors

When agents are low or out of a particular resource, the robot agents can supply them more. The robot agents can also remove a certain resource for the agent depending on the situation. When an agent's fuel falls below a certain percentage, this means that the agent has no more endurance to continue with mission, the agent goes into the fatigued state and the mission fails. When resource X (water) is at five percent or lower, need resupply from robot, the agent will enter a fatigued state and the agent's marksmanship will be decreased by 10 percent. When resource Y (batteries) is at 15 percent or lower, the agent will need resupply from the robot agents, there will also be decreased communications and increase in the agent's vulnerability. When resource Z (MREs, other supplies) is at 15 percent or lower, the agent again will need resupply from the robot agent and will enter the rest behavior.

The property tab display, Figure 11 highlights the various attributes a platoon, MG, or mortar agent can possess. In various triggered states, the agents' vulnerability and/or detectability is either increased or decreased as explained. For instance, when an agent goes into the rest or fatigued state, its vulnerability and detectability is greater.

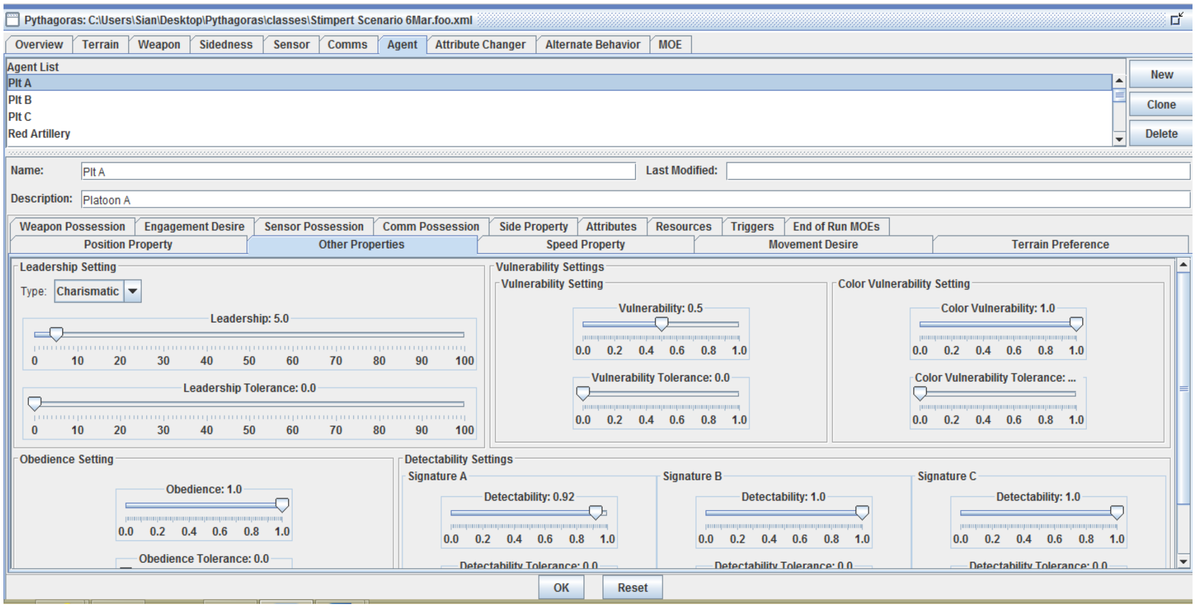

Figure 11. Platoon Property Tab Display

4. Their Triggers and Measures of Effectiveness

These items will capture the behaviors of the agents. A trigger is a state of occurrence that will influence the agent's behavior within the model. An MOE in Pythagoras is the set of values that is captured once the simulation run is complete. This data and set of criteria will assist in determining a suitable recommendation (Stevens 1979). These MOEs will be used to attempt to answer the objective research questions stated above. The run will capture Red Killed, Blue Killed, Blue Final Fuel, Res X, Y and Z used and Res X, Y, and Z final amount for each agent.

When the resources run low as explained in the previous section, this triggers the agents to request resupply from the robot agents. The agents enter the fatigued and rest states until they are replenished by the robot.

5. Initial Case Scenarios

a. Baseline Case Scenario

For this study, the baseline model will not include the use of robots and will only have the attributes of a typical Marine in a rifle platoon, MG section and Mortar section.

They will proceed through the scenario as mentioned in the description of the scenario above. They will not have the capability of resupply from the robot agents and must carry the entire load capacity for a three day mission.

b. Minimum Case Scenario

A minimum number of robots, in this case approximately one robot per squad, for a total of three robot agents will be included in the model. Again, this grouping of agents will run through the exact same scenario much like the platoon, MG section and Mortar section agents as previously mentioned.

c. Maximum Case Scenario

The maximum model will include more than the three robots utilized in the previous model. An entire squad of robots, for a total of 12 robots per platoon will be used in this model.

6. Follow-On Case Scenarios

a. Nine Robot Case Scenario

A step down from the maximum case scenario, this case scenario will include nine robots in the rifle platoon or three robots per squad.

b. Six Robot Case Scenario

A median between the minimum case scenario and the nine robot case scenario is to include six robots. With this case ideally two robot agents will be assigned per squad.

F. MODEL APPROACH AND METRICS

The planning for the simulation model first took shape in the form of a spreadsheet with associated tabs for the Blue Force Structure, Red Force Structure as well as Weapons, Sensor, and Communications, including information such as rates of fire and movement speeds, Appendix C.

All the specifications and researched information for weapons and weights, calculations for all platoons, MG, and mortar sections' logistics for three days' supplies is summarized in Appendix D. These calculations are based on infantry perspectives, Appendix B and the Marine Energy Assessment Team (MEAT) report (Moore et al. 2011). Once the model planning process is complete, the Pythagoras interface is updated with the information reflected in the correct units for the simulation to run properly.

Once the Blue force secures Dakar and reaches Waypoint 5 (WP5), the simulation is complete and data such as number of red agents killed and amounts of resources used, as well as other metrics are compiled into a document for each parameter or MOE observed, Appendix F. The metrics include fuel consumption, water consumption, and distance travelled the final end state of the platoons and how much supplies or resources are left. Once the scenario simulation run is complete, the fuel (endurance), water, batteries, MREs, medical supplies, special tools and POL of the three platoons is reported and compiled into a spreadsheet and parsed. Statistical analysis with the aid of graphs and charts derived from the data collected will serve as the foundation for the analysis and interpretation portion of this study and will be discussed in Chapter IV.

IV. ANALYSIS AND INTERPRETATION

A. INTRODUCTION

In this chapter, we present, analyze, and interpret the simulation data from our experiments. Graphical and statistical evidence will support the proposed recommendation in the next chapter. The results of this study provide a baseline for examining the impact of integrating robotics in more operations. This initial effort offers a simple scenario that can be altered or tailored for more advanced research.

The resulting framework for integration will provide a basic understanding of how robotics will benefit a USMC unit. Observations within the case scenarios offer insight as to how the platoons are able to reach the objective and extend their range and capabilities further than expected. If successfully integrated, robots will enable the platoons to improve their operational reach and effectiveness.

B. DEFINING THE MEASURES

1. The Metrics

Measures, metrics, and factors used in this study provide insight into the integration of robots into the rifle platoon. This analysis is the basis for the framework of integrating LS3 robots into a rifle platoon. Our assertion is twofold--by integrating robots into the rifle platoon, the platoon will greatly benefit in terms of conserving energy, thus gaining or improving operational reach and effectiveness. Figure 12 depicts the desired outcomes in hierarchal form. The metrics that support these outcomes include final distance from the objective or Waypoint 5, final percentage of red dead, final percentage of blue dead, fuel used, and amounts of resources X, Y, and Z used.

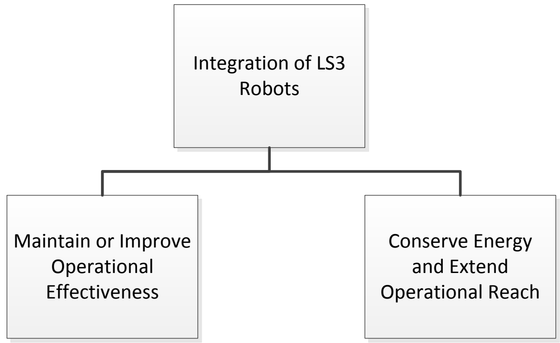

Figure 12. Desired Outcomes through Integration

Success in this study is defined by how close to the target the agents end or their position relative to the final objective, WP5, as well as the attrition of red agents. The agents need to be within at least two and a half kilometers, use less than 50 pounds of each of the resources, kill at least 75 percent or more of the red hostile agents, and maintain their own blue forces. The simulation is set at a maximum of 50 percent of blue forces killed at which time it will go into the rest state.

Comparing the metrics to each other creates measures of particular interest. They include distance away from final objective per total amount of resources X, Y, Z and fuel consumption, percentages of agents killed by distance away from final objective, and distance from final objective divided by total time travelled. The MOE categories are highlighted below.

1. Operational Reach: Distance from objective per amount of resources used. We examine the relative amount of resources to achieve closer proximity to the objective. The ratio of distance per amount of resources used will favor cases in which the value is larger than the other cases. To evaluate this measure fuel, water, batteries, and consumption of other supplies are linked to distance from the final objective.
2. Operational Effectiveness (Combat): Distance from objective per red killed or blue killed. Percentage of red killed or blue killed per amount of resources used also defines this measure. To evaluate this measure, percentage of red killed should increase, while percentage of blue killed should decrease. Relative to these attrition percentages, distance from the objective should be minimized. Similarly, the percentage of resources consumed should be minimized.

Comparison of the case scenarios using these measures will provide an understanding of the impact that robotic integration has on rifle platoon operations in terms of operational reach and effectiveness.

2. Weight Reduction

The load out per robot agent changes within each case scenario. There is an associated weighted load value for each resource per agent. As planned, as the robot agents' load increases, the load for the platoon, MG, and mortar agents' decreases.

Appendix D summarizes the cargo capacities in pounds for water, batteries, and other supplies respectively. Weight reduction per case is calculated using the total weight the robots carry divided by the total weight for all blue agents for three days. Table 7 highlights the weight reduction from the platoon's weighted load as well as the fuel units the agents initially start with in each case. Case Three with 12 robots has the most weight reduction with 90.7 percent.

Table 7. Weight Reductions and Fuel Load for All Cases

Case	Weight Reduction	Fuel Units (per agent)
1	0.0%	3500
2	22.5%	4288
3	90.7%	6675
4	68.60%	5902
5	45.80%	5101

C. PRESENTATION OF DATA/ PROCESS OF ANALYSIS

1. Data Collection

In addition to the three initial case scenarios explained in Chapter III, two follow-on case scenarios were included in the data set. A total of 50 simulation runs per case were used, Appendix F. The data was first separated between platoons and weapons platoon. The total agents killed for the red force as well as the blue force was tallied and recorded. Distance from objective or WP5 appears in pixels, but is converted to meters.

Finally, the percentage of red and blue agents dead is calculated at the end of the simulation run. For this study, Table 7 outlines the allocated number of robots per case scenario with the nomenclature to which each case will be referred to from here on.

Table 8. Five Case Scenarios with Associated Robot Count

Case	Number of Robots	Nomenclature
1	0	R0
2	3	R3
3	12	R12
4	9	R9
5	6	R6

2. Quality Control/Data Refinement

Quality control of the post-processed data is critical. This study will pay particular attention to the trends and statistics of the three rifle platoons, A, B, and C for each case scenario. Special attention will be given to the individual resources X, Y, and Z or water, batteries, and other supplies as well as red and blue agents killed. All values for each resource metric appear in pounds and the number of red and blue agents dead was converted to attrition rates or percentages.

3. Preliminary Analysis

Descriptive statistics provide a basis for more advanced analysis to occur. Statistics on the metrics provide a quick look as to the trends that may arise within the data and comparisons can then be drawn. Quick looks of the data illustrate that by integrating robots, the burden of weight is indeed lifted and the blue agents are more effective in engaging the enemy. A greater percentage of hostiles were killed as more robots were incorporated. We attribute this to less fatigue and greater endurance on the part of the blue force.

Scatter plots and bar graphs are used to display all resources used, percentage of resources used, percentage of agents dead, and distances from the objective. Parsing the data in this manner enables a visual interpretation of the data.

As stated in the previous chapter, all cases ran a consistent simulation time of 72 hours or 12960 time steps with two rest periods. With varied number of robots in each case, the values clearly have certain trends on the percentage of red dead, percentage of blue dead, and the amounts of fuel and resources used. Initial results from the data in all case scenarios include:

- All Red Militia agents were completely killed at the end of each run.
- Distance from WP5 decreased as the number of robots integrated increased.
- Implementation of R3 had counter intuitive results, having the least amount of fuel used including R0.

Table 9 presents the summary of averages for the metrics and measures within each case. The data is separated into the two main desired outcomes.

Table 9. Summary of Averages for Metrics and Measures

Summary of Averages								
	Number of Robots	Distance Away from WP5 (km)	Res X Used (lbs.)	Res Y Used (lbs.)	Res Z Used (lbs.)	Fuel Used (lbs.)	%Red Dead	%Blue Dead
Case 1	0	2.952	40.2582	28.1786	25.1605	132293.2815	73%	48%
Case 2	3	2.6784	35.6956	24.9851	22.3087	120918.4209	86%	54%
Case 3	12	2.4816	37.8203	26.4716	23.6364	134661.7861	97%	40%
Case 4	9	2.4224	37.0486	25.9316	23.1541	129137.6501	95%	45%
Case 5	6	2.482	35.8514	25.0939	22.4060	124061.196	92%	50%

D. OPERATIONAL REACH ANALYSIS

In the simulation, the integration of robotics into the rifle platoons clearly shows the capability of the platoon to arrive closer to the objective without using an excessive amount of resources. As the robots are added, the weight of the resources the platoons

must carry decreases. In effect, the platoon consumes less water, batteries, and other supplies. The platoons are able to go further in the mission and cover more terrain, in other words gaining operational reach.

Resources X, Y, and Z all follow a similar pattern as seen in Figure 13. R3 and R6 use the least amounts of resources and R0 uses the most amounts of these resources. We discover that as the number robots increases, the amount of resources also increases. It had been assumed that with the incorporation of more robots, a fewer amount of resources would be used. However, we recognize that with an increase number of robots the platoon travels further and engages the enemy more frequently, which requires more resources to be consumed.

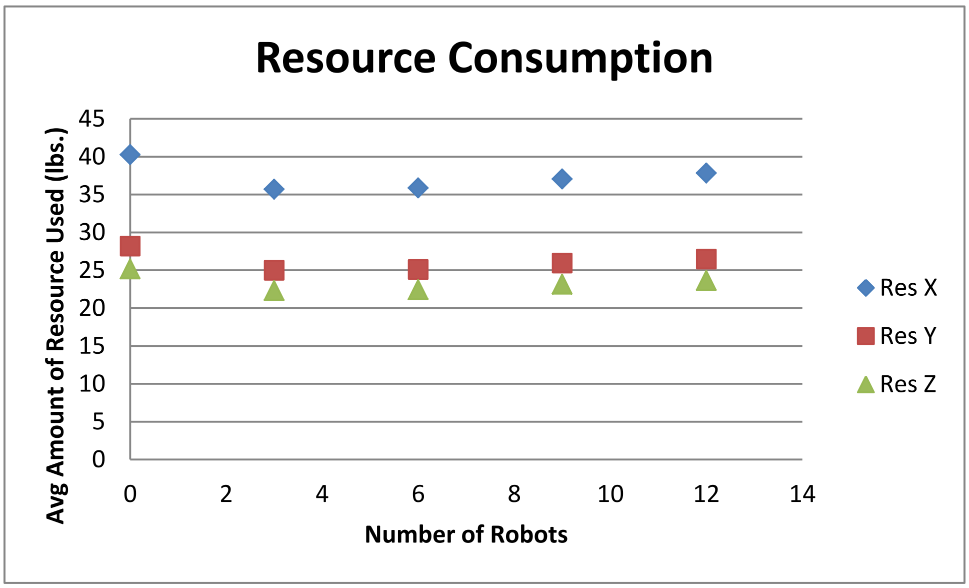

Figure 13. Resource Consumption for Resources X,Y, and Z for All Cases

The percentage of resources used in Table 10 corroborates Figure 13 as to how resource requirements change when robots are integrated into the platoon. Percentage of resources used is calculated from the total amount used divided by the total amount available. Table 10 summarizes these percentages for each case. Again, R0 consumes the

most of resources X, Y, and Z, while R12 has the next highest consumption percentage. The percentages show a greater delineation between cases. Figure 14 displays the information graphically.

Table 10. Percentage of Resources Used by Case

Percentage of Resources Used					
	Case 1 (R0)	Case 2 (R3)	Case 3 (R12)	Case 4 (R9)	Case 5 (R6)
Res X	76%	22%	38%	31%	22%
Res Y	75%	22%	40%	32%	23%
Res Z	13%	5%	10%	8%	5%

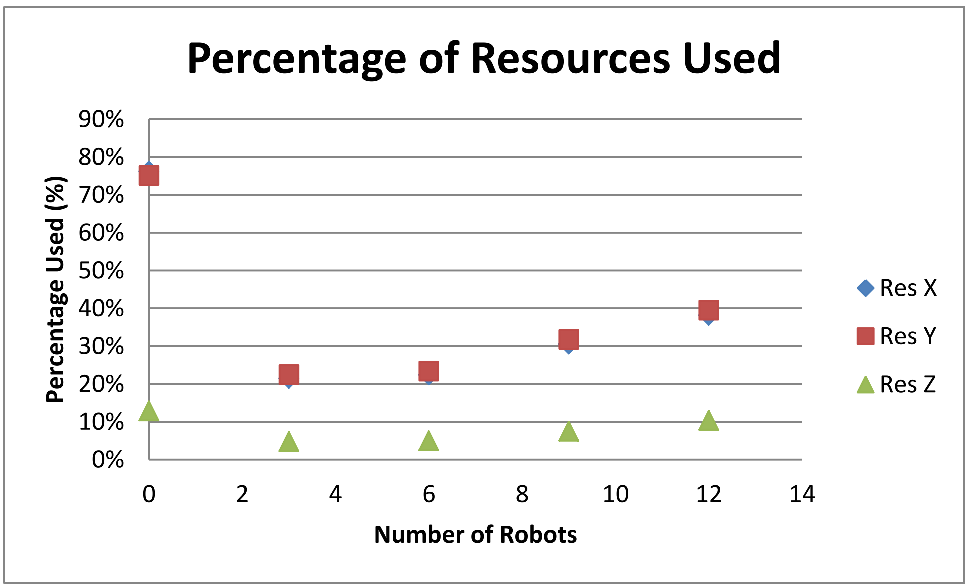

Figure 14. Percentage of Resources Used for All Cases

1. Resource X: Water

Water is a very important resource to Marines when they are on patrol. It is clearly seen in Figure 13 with resource X showing the highest consumption of any of the resources. From Figure 14, it is also easy to see that with R3 and R6, the percentage of water usage is the lowest with 22 percent, while R0 is at the highest with 76 percent. R12 has the second highest percentage out of all the cases. To extend the platoon's operational

reach, water must be conserved. It is evident that integrating these robots reduces water consumption, thereby increasing the platoon's operational reach.

Figure 15 compares distance away from WP5 to percentage of resource X used. R0 shows a higher percentage than all other cases and is the furthest away from the objective. Meanwhile, R6 and R9 are much closer to the objective and use less than 30 percent of water available. R12 and R6 show very similar distances away from the objective, but the percentage of water used is significantly different. The t-tests in Appendix G show that R6 uses significantly less of resource X than R12, but insignificant in the distance from WP5.

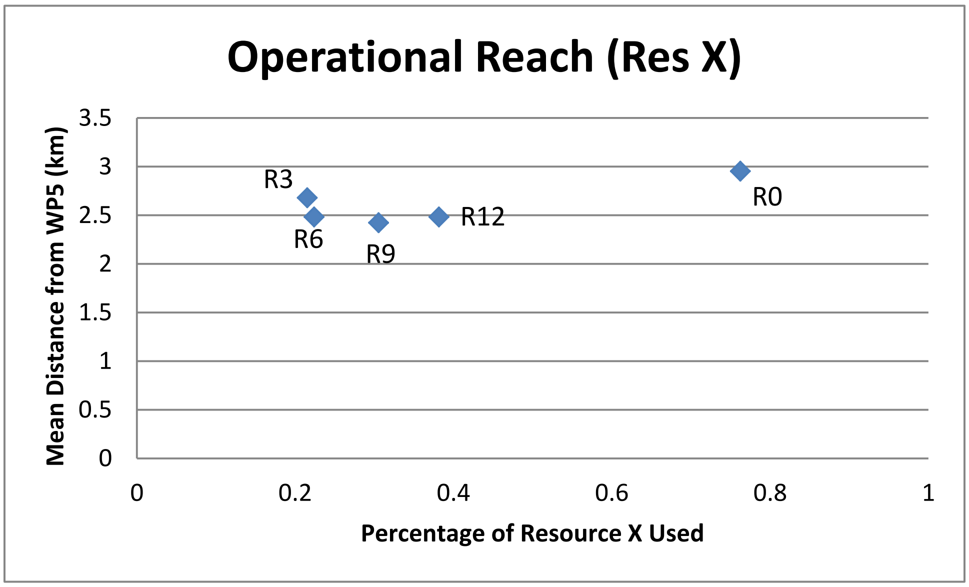

Figure 15. Operational Reach of Resource X

2. Resource Y: Batteries

Another important capability to a mission is the ability to communicate with main base or higher authority. Therefore, replenishing batteries for the radios is critical. Resource Y ranges from 25 to 28 pounds used, showing that with the inclusion of robots, battery usage remains approximately the same, Figure 13. However, even though usage is similar, cases with robots use fewer batteries and perform better than R0. Figure 16 illustrates that R3 through R12 reach WP5 in a shorter distance as compared to R0. R9 is

the closest to WP5 with 32 percent of resource Y used. R6, R9, and R12 are again closer to the objective and use less than 40 percent of batteries available. Their performance in combat is also better and is explained further in the next section.

Resource Y looks very similar to resource X, since these two resources are used the most by the Marines on a scouting and patrol mission. Again, since the platoon is able to extend its reach, more communication with headquarters is required. With the addition of more robots, the platoon is able to reduce the battery usage, which may be attributed to the platoon's alertness and ability to work better internally, thus reducing the need for platoon-level communications. Although R12 and R6 are similar in distance, the hypothesis tests performed shows that R6 uses significantly less of resource Y than R12.

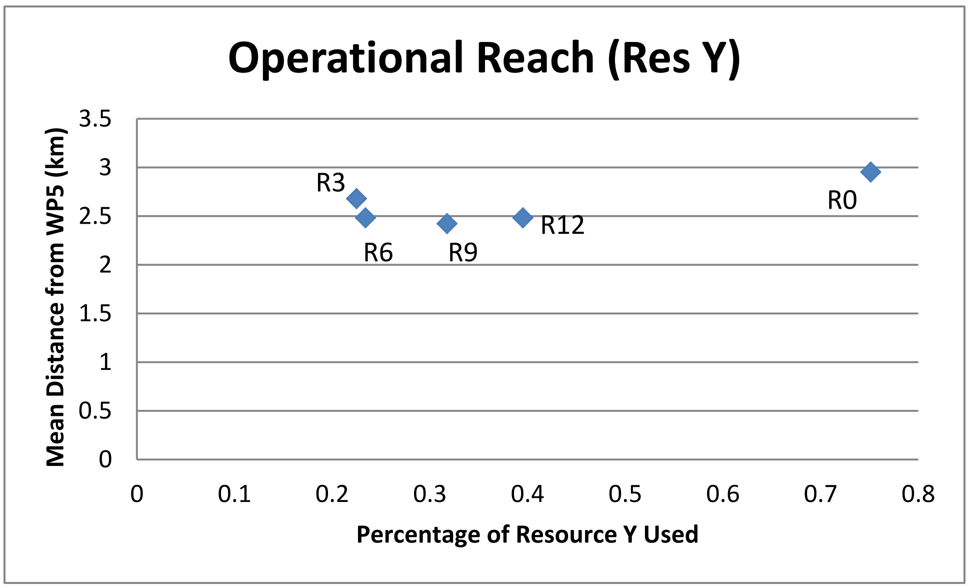

Figure 16. Operational Reach of Resource Y

3. Resource Z: Other Supplies

The use of other supplies such as rations, medical and special tools are not nearly as important as water or batteries to the platoon as seen in Figure 13. Resource Z has the lowest consumption percentages over all cases. Table 10 shows that R3 and R6 are at five percent. We note that a resource X and Yare singular consumables, while resource Z is a grouping of consumables. While not as significant as resources X and Y, the use of

resource Z still has an impact on the operational reach of the platoon. The inclusion of robots still shows that cases with robots use fewer amounts of resource Z as compared to R0, Figure 17.

Figure 17 illustrates a different pattern in comparison to the other two resources seen in Figure 15 and Figure 16. Overall, the percentages are much lower, with a trend of increasing increments of two to three percent as the number of robots increases. This dispersion may possibly indicate greater differences between cases. Looking at Appendix G, the t-tests show that with resource Z or other supplies, R6 uses significantly less than R12. However, R6 and R12 achieve similar distance from the objective. R3 and R6 are not significantly different even though both cases have the least percentage of resource Z used, Appendix G. By integrating robots into the platoon, operational reach is increased with minimal expenditure of resource Z.

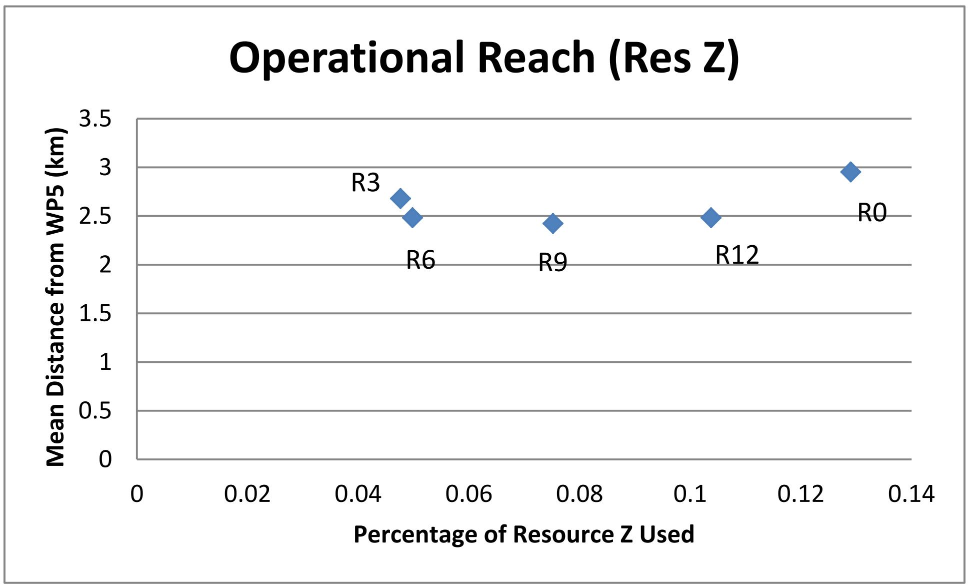

Figure 17. Operational Reach of Resource Z

Across all figures, R9 has the shortest distance away from the objective at 2.42 km. R0 and R3 are clearly at the furthest distances from WP5 for all resource used percentages as well as mean distance away from the objective. R6, R9, and R12 perform better than R3 and R0 in terms of reaching the objective. Still, across all cases as the

inclusion of robots increases, resources X, Y, and Z show reduced usage. This indicates that the integration into a rifle platoon can significantly extend their operational reach.

4. Fuel /Endurance

Fuel usage is examined for both robot agents and platoon agents. Recall that fuel is defined as endurance for the platoon agents as well as the consumption of the actual resource (diesel) for robot agents. As previously stated the LS3 robot consumes nine gallons or 75 pounds of diesel per day and for a 72-hour mission, which is equivalent to 225 pounds. The robot agents had a standoff distance from the platoons of 200 meters. We are sensitive to the fuel usage of the robot agents. There may be a point of diminishing returns if the fuel consumption by the robots burdens the platoon to carry significantly more diesel. Data shows that robot fuel consumption was very consistent over all cases, Table 11, representing a small fraction of the overall fuel consumption of the rifle platoon.

Table 11. Fuel/Endurance Usage of Blue Agents

Fuel/Endurance Used by Blue Agents					
	Case 1	Case 2	Case 3	Case 4	Case 5
Platoons	132293.3	120918.4	134661.8	129137.7	124061.2
Robots	0	203.412	204.888	205.332	204.885
Total	132293.3	121121.8	134866.7	129343	124266.1

Figure 18 depicts the fuel consumption of both platoon fuel units (endurance) and robot agents' diesel consumption combined from Table 11 and separated by case scenario. It is apparent that R3 has the least amount of fuel used by both platoon and robot agents with a combined total of 121,122 units. Interestingly, R0 has the second highest amount since the platoon agents must use all of their endurance without the assistance of robots. R12 with the most robot agents must carry their own diesel fuel. Fuel/endurance usage of R6 and R9 fall in between the minimum and maximum.

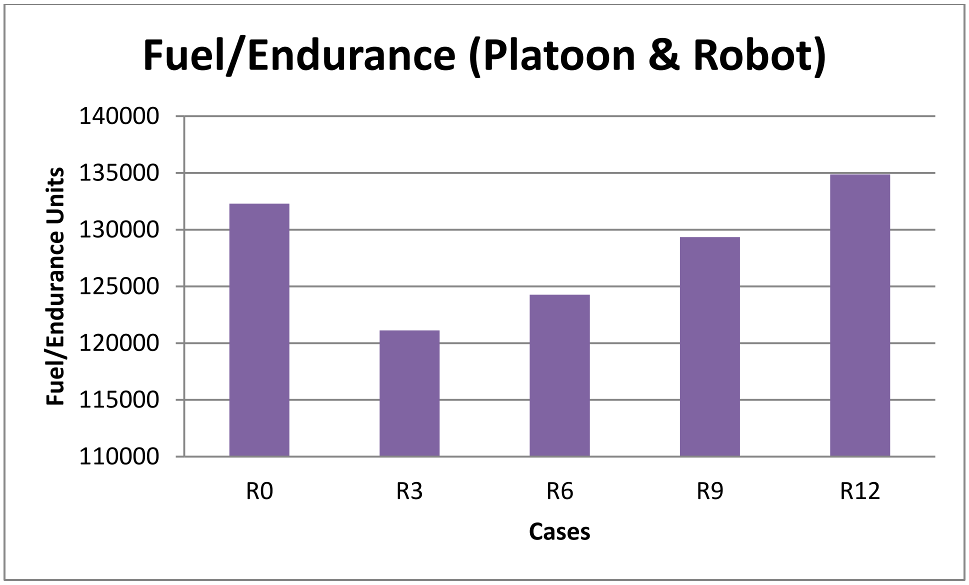

Figure 18. Robot-Platoon Fuel/Endurance Case Comparisons

The high fuel usage in R12 can be attributed to the platoon engaging more hostile enemies, requiring more fuel and endurance. Where R3 appears ideal as far as fuel usage is concerned, R6 and R9 perform better in reaching the objective as seen in the previous sections. These two cases fuel usage is lower than R0 and R12. This fuel analysis corresponds with the resource analysis in terms of extending the platoon's operational, which has a direct link towards operational effectiveness.

E. OPERATIONAL EFFECTIVENESS ANALYSIS

Operational effectiveness is based on the platoons' ability to engage the enemy and achieve the mission objective. With the integration of robots in the simulation, the platoon agents are able to destroy more of the enemy, while still maintaining their force strength or reducing their losses. As in the previous sections, rifle platoons with robots are closer to the final objective.

Table 12 shows that as the number of robots increases the red attrition rate increases and blue attrition rate decreases. R12 has the most kills on the enemy opposition and the least amount of deaths for the blue force. This is credited to the agents being less fatigued from the loaded weight, thus they are able to engage the opposition longer and faster. For R0, there are no robot agents to unload their weight, thus blue

forces are more fatigued and engagement results in the smallest percentage of red killed. Interestingly, R3 has the highest blue attrition. Such a high attrition rate can be attributed to the platoon getting closer to the final objective, and they must engage more of the enemy. However, the number of robots does not completely offset their fatigue to be effective against the enemy. The appropriate number of robots appears to lie between R6 and R9.

Table 12. Attrition Rates for Red and Blue Agents

Average Percentage of Dead Agents			
Case	Nomenclature	Red Force	Blue Force
1	R0	73%	48%
2	R3	86%	54%
3	R12	97%	40%
4	R9	95%	45%
5	R6	92%	50%

Figure 19 shows the attrition percentage of each agent group graphically, blue and red agents respectively.

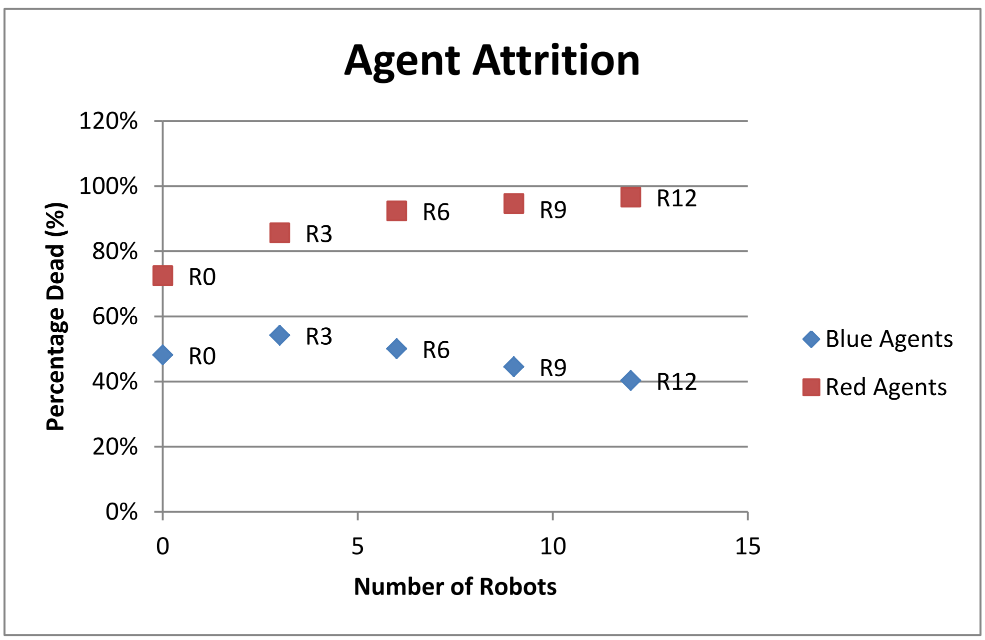

Figure 19. Percentage of Blue and Red Agents Killed for All Cases

The cases are compared with each other to show which one comes closest to the objective, Figure 20. As the number of robots increases, the distance away from WP5 decreases. With a lighter load, the fatigue of the platoon is reduced and their ability to engage the enemy is increased. Therefore, the blue agents are able to extend their operational reach and arrive closer to the objective.

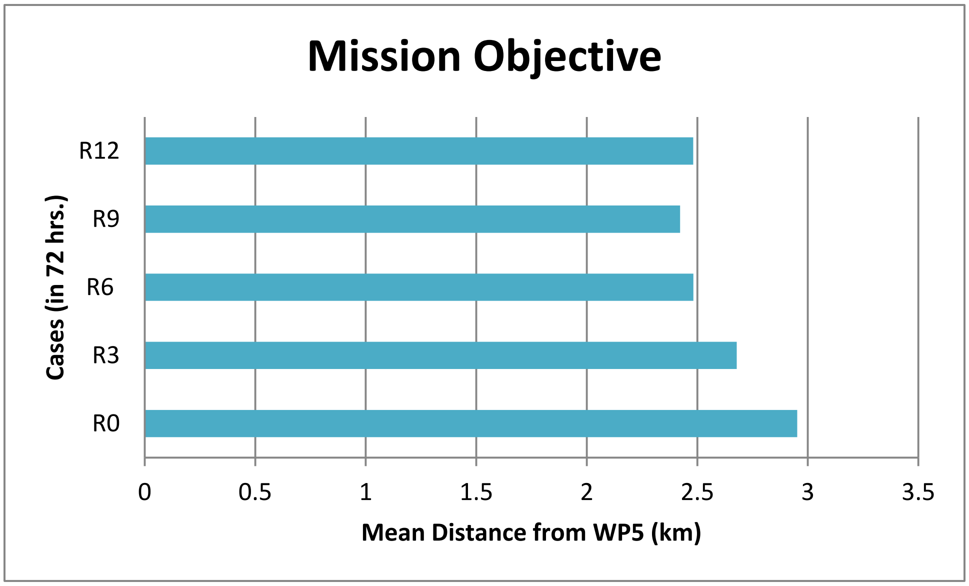

Figure 20. Distance from Final Objective for All Cases

As robots are integrated, the platoons are able to get closer to the objective. In Figure 20, R9 shows the smallest distance away with an average of 4.42 km in 72 hours, but R12 and R6 are not that far off with an average of 2.48 km each. R0 shows the blue agents furthest away from WP5.

R0 and R3 are the farthest away from the objective at 2.95 km and 2.68 km respectively. According to this study's term of mission success, they are outside the range of 2.50 km. In these cases, the platoon fails to complete the mission. R12 and R6 are closest at 2.48 km. This distance is within the mission-success range of 2.50 km, which make these cases appealing.

Combat effectiveness is also attributed to the resources the agents consume. With less resources used by each Marine, the platoon is able to engage the enemy longer and

more frequently. Comparing the percentage dead versus the resources used provides another way to illustrate operational effectiveness. Separated by each resource, Figures 21-23 show this measure.

In Figure 21, R12 has the highest and lowest percentages for red and blue dead, while using an average amount of 38 pounds of resource X. R0 has the smallest red kill percentages and highest blue kill percentages and uses the most amount of water.

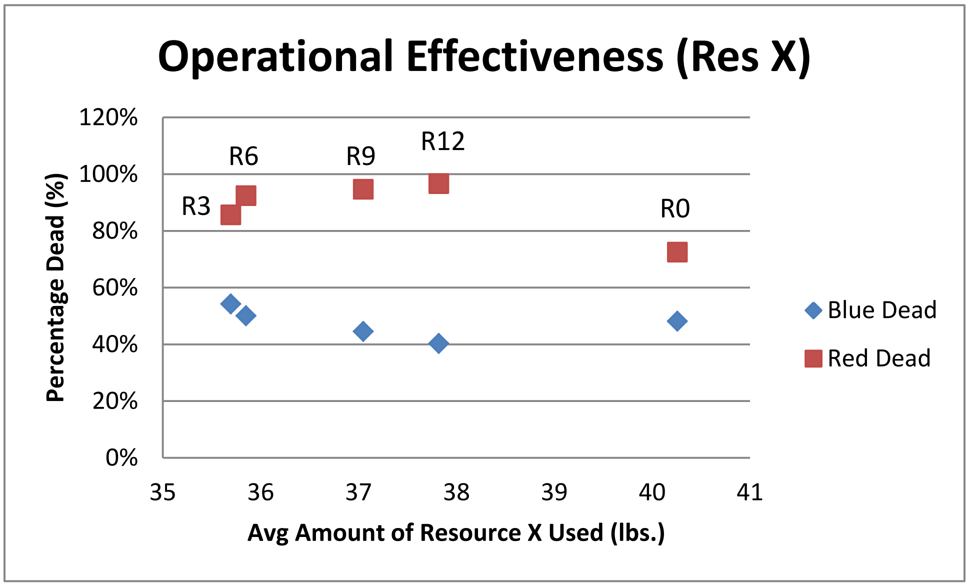

Figure 21. Operational Effectiveness of Resource X

Figure 22, similar to resource X, R0 has the highest and lowest attrition rates and uses the close to 28 pounds of batteries. R9 is close to R12 with the second highest red kill percentage and the second lowest blue kill percentage again with a moderate amount of resources used. R6 uses a small amount of resource Y and still maintains its blue force at 50 percent with red attrition at 92 percent.

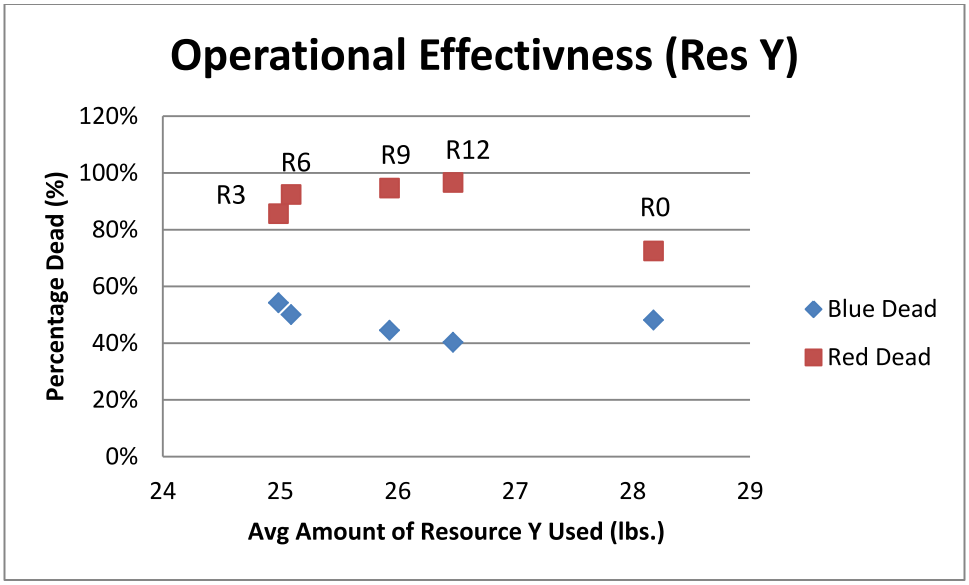

Figure 22. Operational Effectiveness of Resource Y

From resource Z, once again, R0 performs the worst in comparison to R3 through R12 as seen in Figure 23. Like the other resources, R3 uses the least amount of resource Z. However, R6 uses approximately the same amount as R3, yet it has a better red attrition and blue percentage dead than R3.

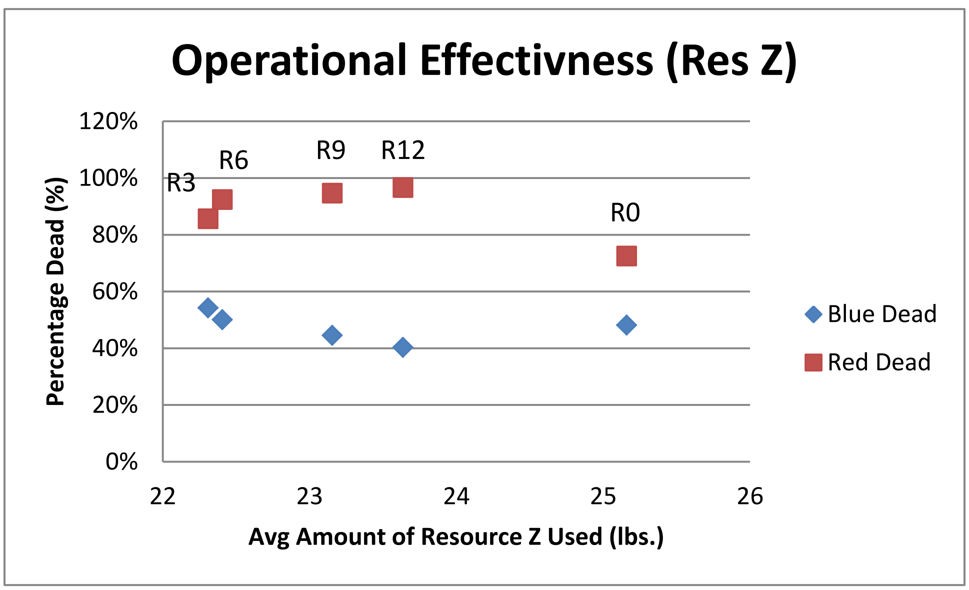

Figure 23. Operational Effectiveness of Resource Z

As more robots were included in each case, the red attrition increased and fewer blue agents died. As a result, the blue force maintained their strength, while maximizing their combat engagements. They also completed the mission by arriving closer to the final objective. They accomplished both of these tasks while consuming a small amount of all resources.

Integration of robots into the rifle platoon operations has a significant benefit. According to the t-tests in Appendix G, R9 performs better than R6 in both red and blue attrition rates. In terms of resource consumption over resources X, Y, and Z, as the number of robots increases, combat effectiveness improves in comparison with R0. Each case is compared even further below.

1. Case One: No Robots

In this case, no robots were included. Therefore, the platoons had to carry their entire load while engaging the enemy. The burden of weight causes exhaustion and less operational effectiveness. Percentage of red agents dead in this case was the lowest out of all the cases with a 73 percent. With this case, each Marine is carrying upwards of 100 pounds, thus causing fatigue, which leads to increased vulnerability and poor marksmanship in the simulation.

2. Case Two: Three Robots

This case scenario is better than the baseline case scenario in regards to red agent attrition at 86 percent. However, it had the highest percentage of blue agent attrition at 54 percent, which is greater than the 50 percent success threshold that this study implements. The interpretation of the t-tests for red and blue agent attrition shows that R3 performs significantly better than R0, Appendix G.

This case shows that it benefits to have robots in the platoon as compared to R0 when it comes to engaging the enemy. Recall that this case reduces the loaded weight by 22.5 percent. While this case scenario performs better than the first case, the other case scenarios show more potential in terms of mission accomplishment and reduced resource consumption overall.

3. Case Three: Twelve Robots

This maximum case clearly shows the extreme as it allows the blue platoon agents to engage the enemy much more frequently and forcefully with a red dead percentage of 97, Table 12. R12 outmatches the other cases by having the least amount of blue agents killed at 40 percent. R12 proves that the agents were able to maintain their own forces while maximizing red opposition death rates. The blue agents were able to accomplish this due to a lighter load per Marine, resulting in greater marksmanship, less exhaustion and less vulnerability.

Even though this case appears to be ideal, it leads to questions of plausibility in actual combat operations. Twelve robots is a huge undertaking for the platoon to handle. It creates a burden for the platoon to assume LS3 operations and maintenance responsibilities. This case, while it provides the platoon with the most capability to alleviate the entire load may be extreme.

4. Case Four: Nine Robots

This case appears to provide a good balance between alleviating the platoon's loaded weight and increasing it operational effectiveness. R9 has a respectable red agent kill rate with 95 percent. R9 also shows the next lowest blue agent kill rate with 45 percent. These exceed the success threshold values defined in this study.

This case comes closest to the final objective as compared to R12. Over resources X, Y, and Z, R9 outmatches R12 with lower percentages and amounts used. With the smaller amounts of resources used, R9 is able to extend the platoon's operational reach and improve operational effectiveness.

5. Case Five: Six Robots

This case rests in the middle of the group. With a red agent attrition rate of 92 percent, R6 out performs R3, but not R9. With a 50 percent blue agent attrition rate, R6 still manages to keep its blue force strength similar to R12. R6 also kills more than 75

percent of the red agents exceeding the success threshold for red attrition. With the integration of six robots, the platoon is able to combat the enemy more frequently and improve its operational effectiveness.

Recalling that this case has a total weight reduction of 45.8 percent, even though it surpasses R3, it does not surpass R9. However, this case uses the second smallest amount of fuel (endurance) meaning they are less fatigued than R9. As a result, the blue agents are still able to achieve a relatively close distance away from WP5 in comparison with the success threshold of 2.50 km.

F. SUMMARY

With an incorporation of robots, the blue agents are able to use less resources and fuel, making it possible for the agents to reach WP5 at a closer distance, thus gaining operational reach. The platoons are also able to increase their combat effectiveness and engage the enemy harder, faster and more frequently with less weighted load. All cases that include robots outperform the baseline case scenario.

Looking at the MOEs from the first section, R9 has best results for operational reach when comparing distance versus amount of resources used and mission accomplishment. The operational effectiveness MOE shows that R12 has the best results with R9 as the next best option.

The operational reach analysis proves that R3 is the best option since it has the lowest percentages of resources used across all cases and the least amount of fuel consumed. R6 has nearly similar percentages for resource usage and the second lowest fuel usage total. However, the mean distance away from the final objective for R6 is less than R3.

From the operational effectiveness analysis, R12 appears to be the best option. It has the highest percentage of red kills and lowest percentage of blue kills. R12 is the second closest to the final objective. R6 illustrates comparable kill rates to R12 and also has nearly a similar distance from WP5.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The loaded weight on a Marine can be alleviated through incorporating weight bearing robots or pack mules. Literature research shows that the LS3 robot had the largest carrying capacity and an acceptable rate of advance to keep up with a rifle platoon during a scout and patrol mission. There are other viable robots, but comparisons were beyond the scope of this study. As result, the LS3 robot was selected for this study in a simulation of the rifle platoon on a scouting and patrol mission.

Modeling and simulation results show that six LS3 robots are able to provide the platoon a 45.8 percent weight reduction, thereby extending its operational reach and improving its operational effectiveness. Analysis shows the trade off in these two measures as the number of robots integrated increases or decreases. As the number of robots is increased, the platoon’s resource consumption decreases while its reach and effectiveness improves. Both are correlated to the weight reduction of the Marines.

This study provides the foundation or baseline for more detailed and advanced studies. The Pythagoras model can be altered or tailored to achieve different objectives depending on what the stakeholder desires. The framework for incorporating robots into a rifle platoon organization is established with this study. An extension of this work can address incorporation of LS3 robots for logistical purposes.

Robotics integration into the rifle platoon gains operational reach and operational effectiveness, key elements of success for the USMC. Graphical analysis and statistics reveals a trade space between six and nine robots per platoon. R6 and R9 perform equally well, but after further interpretations of the data from all five case scenarios, it is evident that six robots (R6) can fulfill the operational needs of the Marine Corps and meet its energy strategy.

B. RECOMMENDATIONS

This study provides a baseline study for the integration of robots into MEU rifle platoons and other fighting military combat units. Other follow-on work could provide even more detail and insight to the current issue of energy consumption.

Follow-on work pertaining to the simulation scenario can be implemented. Improvements include simply applying the model to the other robots such as the BigDog or the WildCat for similar missions. Logistics calculations and rates of advance would need to be adjusted accordingly. Simulation time can be adjusted to a week to ensure all blue agents reach the final objective. Expanding the scenario to a full MEB, MEF, or MAGTF could also be explored. Determining whether this scenario is better suited for a smaller unit or a larger unit would provide the USMC with strong support and leverage in the procurement process.

Conducting an in-depth analysis of alternatives of more robots to include wheeled or tracked robots should be considered. A cost estimation study or analysis on the financial benefits of using the LS3 Alpha Dogs would allow the USMC to see whether or not it is cost-effective to procure LS3 robots. Exploring the human factors side to this study would need to focus on the human-robot interaction with LS3 robots. Finally, the command and control aspect of integrating robots in platoon operations is crucial to the success of the overall mission.

APPENDIX A. PHASES OF LS3 PROGRAM

<table>
<tr><th>Technology</th><th>Phase I</th><th>Phase II</th></tr>
<tr><td>Platform</td><td>Vehicle walk-out</td><td rowspan="7">20 miles of maneuver as referenced in Table 1 LS3 Mission Profile in 24 hours, unrefueled, while carrying 400lb or more

Maneuver includes complex natural/urban terrain and scenes in the presence of a squad of dismounted soldiers

Max vehicle weight = 1250lb, including payload and fuel</td></tr>
<tr><td></td><td>Maneuver at each of the following speeds across even terrain for 400m (parking lot)
• 1mph (expected gait - walk)
• 3mph (expected gait – walk to trot)
• 5mph (expected gait – trot)
• 10mph (expected gait – run)</td></tr>
<tr><td></td><td>Maximum 70 dB noise signature, with 40 dB quiet mode</td></tr>
<tr><td>Controls</td><td>Maneuver at each of the following speeds across uneven terrain for 100m
• 1mph (expected gait - walk)
• 3mph (expected gait – walk to trot)
• 5mph (expected gait – trot)
• 10mph (expected gait – run)</td></tr>
<tr><td></td><td>Stability despite lateral disturbance (kick)</td></tr>
<tr><td>User Interface</td><td>Produce the following foot and body placements detections over a 50m x 2m natural terrain environment
• 95% of poor footholds at 3 mph & 95% of good footholds at 3 mph
• 80% of poor footholds at 5 mph & 80% of good footholds at 5 mph</td></tr>
<tr><td></td><td>Track as moving obstacles up to 5 squad members at 10 Hz with the intent of safe maneuver around and in coordination with them.</td></tr>
</table>

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APPENDIX B. INFANTRY OFFICER PERSPECTIVES

SME #1

-Typically load body armor can weigh close to 60 lbs. and up then add a weapon another 5–10 lbs.

-Thinks that having he Alpha Dogs might be another burden for troops to worry about, more of a logistical burden, doesn't think they are beneficial to USMC

-Already use backpacks that have solar panels on them (300-watt photovoltaic and battery arrangement called the Ground Renewable Expeditionary ENergy System, or GREENS at http://cleantechnica.com/2009/12/11/us-marines-go-greens-with-portable-solar-in-a-suitcase/#85Q3V6ZHAzrCxIE4.99)

-Easier to go in with light loads and have vehicles forward/pre-positioned behind the platoon's position or have helicopter drops for supplies

-Recommends robots would be great if they included counter electronic warfare, jamming counter insurgency capabilities, or ground penetrating radar for IEDs

SME #2

-A rifle platoon soldier can carry total weight of 80–100 lbs.

-Scenario plausible for 2.5 kmph with no real resistance

-Friendly fire support (artillery and mortar) set up inward near route about 10–-17km away from route to cover platoon movement

-Robots should carry water, ammo, batteries, and medical supplies. They should not conduct recon missions, raids are possible

-Likes the idea of the Alpha Dog, but concerned with mobility, reliability, and navigation. Platoon could spare 1–2 guys, but it would take them out of the fight for SA. Manning from platoon, is the robot completely autonomous? Concerned with noise level the robot produces

-Foot mobile platoon is very flexible and can go anywhere, can the robot do that?

SME #3

-Typically load-60-100 lbs. of ammo, water, food

-Plausible scenario to go 30+ km in 3-4 days depending on enemy threat at max 4 kmph

-Since no IEDs in scenario, enemy would not typically want to destroy main roads

-If enemy is known and platoon is making an assault/charge on them, typically an Objective Rally Point is designated and Pack Drop plan is employed and security element if forward deployed/stationed. Possibility to include the LS3 robot here.

-In urban terrain, typically only go in with 30-40 lbs. of gear, drop rucks

-Concerns with robot-noise level, needs to carry ammo, water, food. Typically consume 2 liters of water

-Gunny or LogO should be in charge of robots and possible have 3 people with them

SME #4

-Want robot to carry ammo, water, food and maybe a small 4x2 generator

-Definitely plausible for platoon to travel 30+km in 3-4 days w/o external assistance if they are not overburdened by threat

-Robots would be best suited for the logistical units and planning process might be a burden to the platoon especially in forms of repair and maintenance and carrying all the equipment and tools associated. Concerned with reliability and sustainment

-Integration of robots might throw off training since troops would rely on it more, making them less flexible in combat, doesn't think they are a good idea, just another piece of equipment to worry about

-If the robot were integrated, it would need to be able to traverse mountainous terrain, flooded fields, swamps, muddy, sandy-like terrain since those are the most difficult types of terrain where troops lose a lot of time

APPENDIX C. BLUE AND RED FORCE STRUCTURES, ROBOTS, WEAPONS, SENSORS, COMMS, AND MOVEMENT SPEEDS

Agent	Side	Number of Agents	Movement Speed (km/hr.)	Move Speed (pixels/time step)	Sensor(s)	Weapon(s)
Plt A	Blue	9	4.5	1.25	Eyes; Binos/Sight	M4 or M16A4; IAR or SAW; M203 Grenade Launcher
Plt B	Blue	9	4.5	1.25	Eyes; Binos/Sight	M4 or M16A4; IAR or SAW; M203 Grenade Launcher
Plt C	Blue	9	4.5	1.25	Eyes; Binos/Sight	M4 or M16A4; IAR or SAW; M203 Grenade Launcher
Weps Plt 1st MG Section	Blue	2	4	1.111111111	Eyes; Binos/Sight	IAR or SAW; Howitzer
Weps Plt 2nd MG Section	Blue	2	4	1.111111111	Eyes; Binos/Sight	IAR or SAW; Howitzer
Weps Plt 3rd MG Section	Blue	2	4	1.111111111	Eyes; Binos/Sight	IAR or SAW; Howitzer
Weps Plt 1st Mortar	Blue	1	3	0.833333333	Forward Observer	60mm, 82mm Mortar
Weps Plt 2nd Mortar	Blue	1	3	0.833333333	Forward Observer	60mm, 82mm Mortar
Weps Plt 3rd Mortar	Blue	1	3	0.833333333	Forward Observer	60mm, 82mm Mortar
EFSS 120mm Mortar	Blue	1	2.5	0.694444444	Forward Observer	120mm Mortar

Agent	Side	Number of Agents	Movement Speed (km/hr.)	Move Speed (pixels/time step)	Sensor(s)	Weapon(s)
Robot A	Blue	1	6	1.666666667	Follow-the-leader	None
Robot B	Blue	1	6	1.666666667	Follow-the-leader	None
Robot C	Blue	1	6	1.666666667	Follow-the-leader	None

Agent	Side	Number of Agents	Movement Speed (km/hr.)	Move Speed (pixels / time step)	Sensor(s)	Weapon(s)
Infantry	Red	25	4	1.111111111	Eyes; Binos/Sight	AK-47; RPG-7
Militia	Red	25	3.5	0.972222222	Eyes; Binos/Sight; Forward Observer	RPG-7
Mortars	Red	10	2.5	0.694444444	Forward Observer	82mm Mortar

Robot Agent	Max Load (lbs.)	Max Travel Distance (km)	Max Travel Distance (pixels)	Max Travel Time (hrs.)	Max Travel Time (time steps)
Robot A	400	32.2	1610	24	0.133333333
Robot B	400	32.2	1610	24	0.133333333
Robot C	400	32.2	1610	24	0.133333333

Communication	Max Range (km)	Max Range (pixels)	Line of Sight (Y/N)
Radio	50	2500	Y
Voice	1	50	Y

Sensor	Range (m)	Range (pixels)	Sensor Type
Eyes	1000	50	A
Binos/Sight	2000	100	A
Forward Observer	8000	400	A
Radar	40000	2000	C
Helicopter	80000	4000	B
Eyes-Degraded	500	25	A
Binos/Sight-Degraded	1000	50	A

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APPENDIX D. LOGISTICS SUMMARY FOR FUEL AND RESOURCES

Agent	CASE 1: Total Fuel Capacity	CASE 2: Total Fuel Capacity	CASE 3: Total Fuel Capacity	Case 4: Total Fuel Capacity	Case 5: Total Fuel Capacity	Rate of Advance (km/hr)	Fuel Consumption (units per time step)
Plt Agents	3500	4286	6674	5902	5101	3.5	19.44444444
MG Section Agents	3500	4286	6674	5902	5101	3.5	19.44444444
Mortar Agents	3500	4286	6674	5902	5101	3.5	19.44444444
Robot(s)	3500	4286	6674	5902	5101	3.5	19.44444444

Agent	CASE 1: Total Res X Capacity (Water)	CASE 2: Total Res X Capacity (Water)	CASE 3: Total Res X Capacity (Water)	Case 4: Total Res X Capacity (Water)	Case 5: Total Res X Capacity (Water)	Res X Rate of Consumption (lbs. per time step)
Plt Agents	52.8	44.88	21.12	29.04	42.827	0.004074074
MG Section Agents	52.8	44.88	4.693	6.453	1.760	0.004074074
Mortar Agents	52.8	44.88	2.347	3.227	4.107	0.004074074
Robot(s)	0	95.04	380.16	285.12	179.52	0

Agent	CASE 1: Total Res Y Capacity (Batteries)	CASE 2: Total Res Y Capacity (Batteries)	CASE3: Total Res Y Capacity (Batteries)	Case 4: Total Res Y Capacity (Batteries)	Case 5: Total Res Y Capacity (Batteries)	Res Y Rate of Consumption (lbs. per time step)
Plt Agents	37.5	31.875	15	20.625	30.417	0.002893519
MG Section Agents	37.5	33.75	5	5.833	0.833	0.002893519
Mortar Agents	37.5	33.75	2.5	2.917	3.333	0.002893519
Robot(s)	0	61.875	247.5	185.625	131.25	0

Agent	CASE 1: Total Res Z Capacity	CASE 2: Total Res Z Capacity	CASE 3: Total Res Z Capacity	Case 4: Total Res Z Capacity	Case 5: Total Res Z Capacity	Res Z Rate of Consumption (lbs. per time step)
Plt Agents	195	165.15	75.6	105.45	158.3	0.002546296
MG Section Agents	309	224.1	**12**	**14**	**2**	0.003472222
Mortar Agents	1605	1066.5	**6.2**	**7.233**	**8.267**	0.006404321
Robot(s)	0	1165.365	4661.46	3496.095	2252.61	0

Case Scenarios	Robots per Plt	Capacity of Robots (lbs.)	Suggested Total Robot Weight Platoon (3 Days)	Extra Capacity (lbs.)	Extra Mortar Rounds	Extra Mortars (lbs.)	Extra Weight	Total Platoon, MG, Mortar Weight 3 DOS (lbs.)	Avg % Reduction per agent	Additional DOS possible (%)	Additional % Weight Reduction	Total % Weight Reduction
Case 1	0		Standard load out. Marines get no "endurance" advantage. Can go 3 days with full packs.								0%	0%
Case 2	3	1200	1165.365	34.635	18	63	-28.365	5061.6	23.0%	0.1	-0.6%	22.5%
Case 5	6	2400	1165.365	1234.635	24	84	1150.635	5061.6	23.0%	3.2	22.7%	45.8%
Case 4	9	3600	1165.365	2434.635	36	126	2308.635	5061.6	23.0%	6.3	45.6%	68.6%
Case 3	12	4800	1165.365	3634.635	60	210	3424.635	5061.6	23.0%	9.4	67.7%	90.7%

Extra Weight Specified Amounts for Case 3-5

Case	Total	Water (lbs.)	Batteries	Battery Count	Ammo (30 mag)	Ammo Mag Count	Other
5	1150.635	575.3175	201.361125	322	373.956375	374	201.361125
4	2308.635	1154.3175	404.011125	646	750.306375	750	404.011125
3	3424.635	1712.3175	599.311125	959	1113.006375	1113	599.311125

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APPENDIX E. CASE SUMMARY TRANSLATIONS

Case 1: No Robots			
	Res X Capacity (lbs.)	Res Y Capacity (lbs.)	Res Z Capacity (lbs.)
Platoon	52.8	37.5	195
MG	52.8	37.5	309
Mortar	52.8	37.5	1605
Robot	0	0	0

Case 2: Three Robots			
	Res X Capacity (lbs.)	Res Y Capacity (lbs.)	Res Z Capacity (lbs.)
Platoon	44.9	31.87	165.1
MG	44.9	33.8	224.1
Mortar	44.9	33.8	1066.5
Robot	95	61.9	1141.4

Case 3: Twelve Robots			
	Res X Capacity (lbs.)	Res Y Capacity (lbs.)	Res Z Capacity (lbs.)
Platoon	21.1	15	75.6
MG	4.7	5	12
Mortar	2.3	2.5	6.2
Robot	380.2	247.5	4565.5

Case 4: Nine Robots			
	Res X Capacity (lbs.)	Res Y Capacity (lbs.)	Res Z Capacity (lbs.)
Platoon	29.04	20.625	105.45
MG	6.45	5.83	14
Mortar	3.23	2.92	7.23
Robot	285.12	185.625	3424.095

Case 5: Six Robots			
	Res X Capacity (lbs.)	Res Y Capacity (lbs.)	Res Z Capacity (lbs.)
Platoon	42.827	30.417	158.300
MG	1.760	0.833	2.067
Mortar	4.107	3.333	8.267
Robot	179.520	131.250	2252.610

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APPENDIX F. DATA BY CASES

Case One

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5 (km)
1	2.78	72	36.2979	25.40761	22.68594	113004.7	73%	70%	0
2	3.3	72	37.21003	26.04549	23.25573	117705.7	75%	63%	0
3	3.12	72	34.70389	24.29145	21.68928	111397.7	75%	63%	0
4	2.7	72	41.10264	28.76957	25.68825	128417.4	73%	44%	0
5	2.02	72	38.33831	26.83602	23.96127	118331.3	78%	74%	0
6	2.72	72	35.52913	24.8696	22.20546	110033	78%	70%	0
7	1.98	72	30.7844	21.54881	19.23955	109373.3	80%	81%	0
8	2.88	72	43.44788	30.41057	27.15373	141943.6	55%	37%	0
9	3.24	72	37.58203	26.30578	23.48818	117663.6	78%	59%	0
10	2.44	72	44.30641	31.01163	27.69035	143235.6	67%	37%	0
11	3.22	72	36.32774	25.42814	22.70442	112305	78%	67%	0
12	4.8	72	32.38332	22.66715	20.23919	102546.1	75%	70%	0
13	2.94	72	51.84643	36.28785	32.40201	192998.1	90%	0%	0
14	1.96	72	38.32526	26.82689	23.95312	114813.8	73%	74%	0
15	2.9	72	50.00649	35.00006	31.25212	180378.7	85%	4%	0
16	3	72	50.00604	34.99975	31.25184	186179.6	80%	4%	0
17	2.38	72	38.47205	26.92925	24.04468	121187	62%	70%	0
18	2.4	72	45.44835	31.81067	28.40391	147245.1	63%	30%	0

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5 (km)
19	3.8	72	41.37014	28.95603	25.85506	136307.9	67%	33%	0
20	2.26	72	42.94838	30.0614	26.84176	135738.6	75%	41%	0
21	3	72	45.54593	31.87859	28.46471	152966.8	53%	26%	0
22	2.36	72	34.04863	23.83412	21.28063	103600.1	75%	89%	0
23	2.8	72	43.24367	30.26725	27.02572	147003.4	92%	26%	0
24	2.84	72	46.35483	32.4446	28.97017	152628.9	67%	19%	0
25	3.84	72	38.89907	27.22698	24.31098	127869.3	67%	48%	0
26	5.36	72	39.02402	27.31336	24.38853	145319.9	53%	26%	0
27	2.26	72	35.63268	24.94209	22.27004	110600.2	75%	70%	0
28	2.82	72	32.15812	22.51097	20.09915	97979.29	87%	93%	0
29	3.5	72	42.58316	29.80515	26.61322	142549.6	58%	37%	0
30	2.04	72	42.342	29.63746	26.46304	135051.3	75%	56%	0
31	3	72	47.08004	32.95202	29.42332	158638.6	57%	15%	0
32	2.74	72	40.64706	28.45078	25.40357	129604.4	73%	48%	0
33	2.9	72	38.43862	26.9055	24.0236	123874.5	85%	59%	0
34	2.38	72	42.67805	29.87224	26.67285	136445.9	68%	44%	0
35	3.52	72	44.80584	31.36039	28.00208	151831.1	50%	22%	0
36	2.84	72	44.21666	30.94848	27.63409	143348.9	77%	30%	0
37	3.88	72	41.22249	28.85274	25.76282	138452.8	60%	37%	0
38	3.78	72	36.60272	25.6202	22.87607	117328.5	68%	59%	0
39	4.26	72	32.40949	22.68581	20.25571	101968.1	67%	74%	0
40	3.82	72	35.07088	24.54833	21.91887	109817.9	73%	67%	0

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5 (km)
41	2.46	72	42.05913	29.43918	26.2861	136997	68%	48%	0
42	2.8	72	31.17315	21.82	19.48268	102126.8	75%	67%	0
43	2.84	72	43.01588	30.10827	26.88377	139024.8	72%	37%	0
44	2.28	72	34.80421	24.36166	21.75166	125316.6	85%	63%	0
45	2.04	72	38.11407	26.67912	23.82115	117237.4	72%	74%	0
46	2.4	72	46.1805	32.32296	28.8614	150720.5	78%	26%	0
47	3.8	72	46.31238	32.41453	28.94346	173385.8	82%	11%	0
48	2.68	72	50.05804	35.03615	31.28435	175539.3	87%	4%	0
49	2.68	72	36.40739	25.48373	22.75389	115562.5	73%	59%	0
50	2.84	72	35.34938	24.74391	22.09325	111068.3	72%	81%	0
AVG	2.952	72	40.2583	28.1786	25.16053	132293.3	0.725	0.481481	0

Case Two

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
1	1.84	72	37.88535	26.51786	23.67715	127939.2	80%	52%	2.04
2	2.68	72	35.86417	25.10345	22.41429	119901.9	83%	59%	2.88
3	3.16	72	37.58102	26.30506	23.48752	121938.7	73%	56%	3.36
4	2.34	72	32.08163	22.45622	20.05014	110563.9	75%	70%	2.54
5	1.94	72	32.45668	22.719	20.2846	112695.1	88%	74%	2.14
6	2.5	72	31.72865	22.20888	19.8295	106452.2	92%	67%	2.7
7	2.5	72	31.17654	21.82238	19.48447	102686.3	90%	67%	2.7
8	2.4	72	50.01567	35.00649	31.25786	193153.8	93%	4%	2.6
9	2.14	72	35.39361	24.77378	22.11992	119633.3	88%	56%	2.34
10	2.26	72	36.10402	25.27135	22.56411	121007	80%	59%	2.46
11	3.46	72	29.81008	20.86582	18.63045	98470.01	83%	67%	3.66
12	4.04	72	29.65763	20.75911	18.53515	100777.6	87%	67%	4.24
13	2.6	72	34.90073	24.42876	21.81187	117722.8	87%	56%	2.8
14	4.62	72	21.33067	14.93182	13.33126	76405.74	78%	96%	4.82
15	2.28	72	39.30837	27.51403	24.56686	129048.9	85%	52%	2.48
16	2.58	72	35.13908	24.59561	21.96083	119851.7	80%	56%	2.78
17	2.64	72	38.00728	26.603	23.75345	126816.4	95%	48%	2.84
18	2.24	72	41.74653	29.22037	26.09068	136364.4	80%	44%	2.44
19	2.54	72	40.771	28.53675	25.48045	135799.2	93%	33%	2.74
20	1.82	72	47.2025	33.0381	29.49988	158372	82%	19%	2.02
21	2.54	72	27.42164	19.19475	17.13787	93477.04	80%	81%	2.74
22	2.6	72	32.4526	22.71568	20.28195	116614.5	90%	67%	2.8

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
23	2.58	72	32.12655	22.48743	20.07817	108225.2	90%	67%	2.78
24	2.66	72	45.71086	31.99391	28.56768	152206.4	90%	19%	2.86
25	3.08	72	24.78822	17.35173	15.49211	87169.83	92%	89%	3.28
26	4.96	72	28.58483	20.00789	17.86464	96073.21	80%	63%	5.16
27	2.62	72	37.32067	26.12233	23.3242	128206.2	85%	48%	2.82
28	2.32	72	35.96661	25.17563	22.47859	119397.7	85%	67%	2.52
29	3.14	72	35.62057	24.93244	22.26175	122052.2	85%	52%	3.34
30	1.9	72	35.61756	24.93078	22.25991	121762.3	85%	59%	2.1
31	2.76	72	44.81246	31.36536	28.00638	152303.1	70%	26%	2.96
32	2.26	72	41.96655	29.37416	26.22802	138751.6	85%	41%	2.46
33	3.12	72	21.88669	15.32102	13.67882	75271.05	88%	96%	3.32
34	2.28	72	43.96773	30.77457	27.47863	146759.3	82%	33%	2.48
35	2.58	72	33.19349	23.23409	20.74494	111623	85%	63%	2.78
36	2.64	72	34.21747	23.95068	21.38487	116714.4	83%	59%	2.84
37	2.1	72	33.60785	23.52415	21.00393	113687.2	93%	63%	2.3
38	3.46	72	37.19748	26.03564	23.24714	119488.9	90%	41%	3.66
39	3.42	72	33.98941	23.79057	21.24229	114154.8	87%	52%	3.62
40	3.4	72	34.07232	23.84812	21.2941	114669.3	90%	44%	3.6
41	1.78	72	43.77207	30.63737	27.356	144280.6	82%	30%	1.98
42	2.5	72	31.73087	22.21044	19.83089	108312.5	93%	67%	2.7
43	2.68	72	38.35166	26.84431	23.96893	127848.3	85%	52%	2.88
44	2.2	72	39.02802	27.31731	24.39122	132202.9	90%	44%	2.4
45	1.82	72	42.69594	29.88427	26.68349	142601.2	90%	33%	2.02

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
46	2.98	72	37.25241	26.07432	23.2815	123016.5	90%	44%	3.18
47	2.78	72	48.16373	33.7103	30.10047	169332.7	93%	7%	2.98
48	2.12	72	32.46581	22.72491	20.29022	111779.6	87%	67%	2.32
49	3.44	72	26.68878	18.681	16.67982	93414.35	80%	70%	3.64
50	2.62	72	31.95234	22.36547	19.96929	108925.2	85%	67%	2.82
AVG	2.6784	72	35.69569	24.98517	22.30877	120918.4	0.856667	0.542222	2.8784

Case Three

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
1	2.38	72	40.25178	28.17327	25.15596	142909.1	95%	33%	2.58
2	2.84	72	34.82631	24.37618	21.76533	123567.3	98%	48%	3.04
3	1.96	72	32.38236	22.66601	20.23807	115326.8	97%	59%	2.16
4	2.84	72	36.18582	25.32766	22.61495	129443.9	97%	44%	3.04
5	1.62	72	42.71481	29.89724	26.69528	150541.7	97%	30%	1.82
6	1.92	72	38.61092	27.02507	24.13056	136505.3	97%	41%	2.12
7	3.86	72	33.35318	23.34495	20.84464	118693.7	98%	48%	4.06
8	1.9	72	35.48561	24.83745	22.17743	130376.7	95%	44%	2.1
9	2.4	72	37.85881	26.49857	23.6605	134729.7	97%	41%	2.6
10	2.34	72	35.06335	24.5421	21.9135	124113.7	98%	48%	2.54

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
11	2.28	72	44.73819	31.31299	27.95971	157979.8	97%	19%	2.48
12	4.4	72	29.23152	20.46034	18.26882	103607.4	100%	59%	4.6
13	2.36	72	39.07715	27.35122	24.42188	139202.6	93%	37%	2.56
14	1.92	72	38.49982	26.94729	24.06113	136044.1	93%	41%	2.12
15	2.06	72	38.69181	27.08169	24.1811	138333.9	98%	41%	2.26
16	1.9	72	42.01484	29.40724	26.25781	148257.4	98%	30%	2.1
17	2.4	72	35.63886	24.94499	22.27316	127018.4	100%	48%	2.6
18	1.94	72	39.63564	27.74218	24.77095	140297.7	98%	37%	2.14
19	2.28	72	36.95552	25.86598	23.096	136955.5	100%	37%	2.48
20	1.56	72	42.56978	29.79571	26.60465	151983.2	100%	30%	1.76
21	2.3	72	41.26199	28.88022	25.78729	145612.9	97%	30%	2.5
22	1.96	72	36.1384	25.29468	22.58538	127917.4	100%	48%	2.16
23	1.88	72	40.66836	28.46489	25.41634	144547.7	100%	33%	2.08
24	2.36	72	40.35933	28.24856	25.22318	144718.7	95%	33%	2.56
25	5.04	72	23.18248	16.22697	14.48849	83458.64	93%	78%	5.24
26	3.8	72	35.76275	25.03127	22.35048	126629.7	97%	41%	4
27	2.44	72	33.08635	23.1586	20.67799	117694.4	95%	56%	2.64
28	2.52	72	30.16017	21.11087	18.8493	109116	93%	67%	2.72
29	2.88	72	42.93321	30.04968	26.83166	154222.7	97%	22%	3.08
30	1.96	72	40.93812	28.65373	25.58492	145708.1	97%	33%	2.16
31	3.36	72	40.97683	28.68038	25.60901	145216.9	100%	26%	3.56
32	2.06	72	34.96228	24.47158	21.85037	123741.8	98%	52%	2.26
33	3.5	72	33.29301	23.30306	20.80707	120770.7	98%	52%	3.7

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
34	1.88	72	46.53147	32.56811	29.08043	164244	97%	15%	2.08
35	2.8	72	40.69711	28.4848	25.43424	145021.7	92%	30%	3
36	2	72	39.87044	27.90655	24.91768	142839.8	92%	37%	2.2
37	2.76	72	38.13941	26.69477	23.83583	136558.9	98%	37%	2.96
38	2.86	72	34.81845	24.37068	21.76042	123179.7	98%	48%	3.06
39	4.92	72	29.01611	20.30956	18.13417	104580.8	97%	59%	5.12
40	3.36	72	35.24972	24.67235	22.0299	125018.4	98%	44%	3.56
41	1.94	72	40.94938	28.66161	25.59196	145800.2	92%	33%	2.14
42	2.4	72	32.11347	22.47779	20.07	113995.6	95%	59%	2.6
43	1.96	72	43.03393	30.12041	26.89468	152482.9	98%	26%	2.16
44	1.94	72	43.09289	30.16168	26.93153	152853	93%	26%	2.14
45	1.62	72	44.97283	31.47746	28.10641	159136.5	95%	22%	1.82
46	2.38	72	37.97998	26.5834	23.73623	135470.4	98%	41%	2.58
47	1.88	72	42.07128	29.44675	26.29308	148350.5	92%	30%	2.08
48	1.9	72	35.25441	24.67609	22.03294	125223	98%	52%	2.1
49	2.32	72	42.33603	29.63186	26.4585	150978	97%	26%	2.52
50	1.94	72	37.38029	26.16381	23.36148	132112.3	95%	44%	2.14
AVG	2.4816	72	37.82033	26.47161	23.63645	134661.8	0.966333	0.402963	2.6816

Case Four

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
1	2.56	72	38.50735	26.95258	24.0658	135878.6	92%	41%	2.76
2	3.4	72	34.1564	23.90723	21.34664	117002.2	98%	48%	3.6
3	2.94	72	26.00355	18.20179	16.25162	91339.98	92%	78%	3.14
4	2.36	72	35.41503	24.78829	22.13328	122220.8	98%	48%	2.56
5	1.62	72	41.77423	29.23903	26.10747	144191.1	95%	33%	1.82
6	1.68	72	43.15122	30.20275	26.96801	150297.5	93%	30%	1.88
7	2.44	72	37.9311	26.54918	23.70567	132946.5	93%	41%	2.64
8	1.66	72	39.39563	27.57439	24.62099	137239.8	92%	41%	1.86
9	2	72	39.98984	27.99013	24.9923	140417.6	100%	37%	2.2
10	2.52	72	39.60111	27.71802	24.74933	138569	93%	37%	2.72
11	2.32	72	42.27441	29.58872	26.41999	146697.5	97%	26%	2.52
12	3.4	72	30.99988	21.69825	19.374	107947.9	97%	59%	3.6
13	2.92	72	29.15148	20.40476	18.21889	101266.6	95%	67%	3.12
14	2.42	72	31.49183	22.04285	19.68151	108978.2	93%	63%	2.62
15	2.1	72	34.25384	23.97588	21.40763	120974.8	97%	56%	2.3
16	2.4	72	33.68823	23.57994	21.05413	117531.9	93%	56%	2.6
17	2.02	72	41.12211	28.78253	25.6999	141705.5	97%	33%	2.22
18	2.4	72	36.10046	25.26813	22.56163	125120.3	97%	48%	2.6
19	2.88	72	36.19026	25.33077	22.61772	125409.7	97%	44%	3.08
20	2.3	72	41.40123	28.9777	25.8743	141597.8	98%	30%	2.5
21	2.94	72	33.10751	23.17343	20.69118	116409.2	95%	56%	3.14
22	2.04	72	31.35587	21.94765	19.59657	109340.2	98%	63%	2.24

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
23	2.42	72	35.77544	25.04061	22.35851	124600.1	97%	48%	2.62
24	2.48	72	37.58292	26.30568	23.48809	132461.2	92%	44%	2.68
25	2.96	72	31.99242	22.39306	19.99432	112557.5	95%	59%	3.16
26	3.3	72	38.88695	27.21785	24.30296	136366.7	98%	33%	3.5
27	2.42	72	38.10161	26.66854	23.81223	133088.5	97%	41%	2.62
28	2.08	72	36.97049	25.87718	23.10538	128455.7	88%	48%	2.28
29	2.36	72	44.76233	31.3299	27.9748	157187.5	95%	19%	2.56
30	2.12	72	34.87513	24.41081	21.7959	121155.6	87%	56%	2.32
31	2.4	72	37.17732	26.02174	23.23461	130858.1	97%	44%	2.6
32	2.12	72	31.73317	22.21179	19.83236	111189.2	100%	63%	2.32
33	2.46	72	37.00711	25.90259	23.12824	128247.1	98%	44%	2.66
34	2.1	72	39.04807	27.3311	24.40375	136669	92%	41%	2.3
35	2.86	72	40.94139	28.6558	25.5869	143392.4	95%	30%	3.06
36	2	72	42.41688	29.68869	26.50906	148360.4	88%	30%	2.2
37	2.02	72	35.25649	24.67754	22.03423	122939.5	98%	52%	2.22
38	2.84	72	36.12108	25.28234	22.57449	125725.1	93%	44%	3.04
39	2.88	72	38.44709	26.91017	24.02811	134123.4	95%	37%	3.08
40	2.86	72	41.60214	29.11811	25.99982	143816.1	92%	26%	3.06
41	1.66	72	35.63924	24.94572	22.27346	124519	90%	56%	1.86
42	2.36	72	38.05183	26.63369	23.78113	132521.5	100%	41%	2.56
43	2.46	72	35.92965	25.14856	22.45489	126402.3	95%	48%	2.66
44	2.38	72	39.10396	27.36999	24.43864	134267.6	95%	37%	2.58
45	1.78	72	37.73312	26.41104	23.58202	132411.7	93%	48%	1.98

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
46	2.86	72	38.55316	26.98442	24.0944	133750.8	92%	37%	3.06
47	2.44	72	35.3252	24.72566	22.07714	122515.7	88%	52%	2.64
48	1.96	72	39.07741	27.35163	24.42209	137150.4	95%	41%	2.16
49	2.84	72	38.27392	26.78894	23.91989	133661.9	95%	37%	3.04
50	2.38	72	38.98322	27.28547	24.36319	135405.7	93%	37%	2.58
AVG	2.4224	72	37.04863	25.93165	23.15418	129137.7	0.946667	0.445185	2.6224

Case Five

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
1	2.1	72	34.47041	24.1275	21.54298	119363.1	92%	56%	2.3
2	2.94	72	37.74354	26.41789	23.58842	129131.8	88%	41%	3.14
3	2.06	72	34.68862	24.28025	21.67935	120690.4	95%	56%	2.26
4	1.96	72	42.29023	29.60002	26.42991	143465	88%	37%	2.16
5	1.74	72	37.60143	26.31885	23.49972	130395	92%	52%	1.94
6	2.98	72	34.59471	24.2143	21.62059	120468.9	88%	52%	3.18
7	2.04	72	34.5513	24.18412	21.59353	119695.1	93%	59%	2.24
8	2.02	72	41.36965	28.95582	25.8546	143175.5	87%	33%	2.22

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
9	2	72	45.69947	31.98592	28.56049	157788.4	93%	19%	2.2
10	2.06	72	35.12962	24.58898	21.95495	121958.5	97%	56%	2.26
11	2.4	72	40.26393	28.18178	25.16356	138713.2	95%	33%	2.6
12	2.6	72	35.85613	25.09733	22.40894	125021.3	92%	52%	2.8
13	2.58	72	28.38834	19.871	17.74201	99078.24	95%	78%	2.78
14	2.02	72	31.67881	22.17373	19.79839	108668	95%	63%	2.22
15	2.02	72	40.07265	28.0481	25.04405	136058.8	97%	37%	2.22
16	2.12	72	37.84228	26.48747	23.6502	132341.1	87%	48%	2.32
17	2	72	43.27006	30.28571	27.04225	147082.8	100%	26%	2.2
18	2.06	72	39.31813	27.52015	24.57252	136239.4	90%	44%	2.26
19	2	72	38.75817	27.12815	24.22258	132137.9	98%	41%	2.2
20	3.32	72	36.91246	25.83611	23.06903	125831.7	95%	41%	3.52
21	2.48	72	36.58561	25.60776	22.86482	126956.3	92%	48%	2.68
22	2.06	72	34.50804	24.15384	21.5665	118842.1	93%	56%	2.26
23	2	72	41.25884	28.87825	25.78535	142047.8	95%	33%	2.2
24	2.9	72	33.57488	23.50061	20.98326	117942.6	92%	56%	3.1
25	4.06	72	21.07742	14.75428	13.17301	74382.93	88%	93%	4.26
26	3.9	72	28.83428	20.18273	18.02059	101400.4	90%	67%	4.1
27	3.44	72	28.82838	20.17858	18.01695	99602.69	93%	67%	3.64
28	2.14	72	38.67635	27.07112	24.17145	135454.8	87%	44%	2.34
29	3	72	37.77227	26.43801	23.60638	129675.5	88%	44%	3.2
30	1.72	72	44.44511	31.10828	27.77662	153342.4	87%	26%	1.92
31	2.52	72	41.88386	29.31557	26.17592	145310.6	92%	33%	2.72

Run	Distance Away from WP5 (km)	Time (12960 ts)	Amt Res X Used	Amt Res Y Used	Amt Res Z Used	Amt Fuel Used	% Red Dead	% Blue Dead	Robot Dist Away from WP5
32	2.16	72	30.81757	21.57132	19.26017	108364.8	97%	70%	2.36
33	3.08	72	22.83488	15.9843	14.27138	80105.68	95%	89%	3.28
34	2.14	72	43.84617	30.68901	27.40228	152198.3	93%	26%	2.34
35	3.38	72	26.66205	18.66254	16.66311	92615.78	97%	74%	3.58
36	1.74	72	38.6897	27.08045	24.17982	134112.3	93%	44%	1.94
37	3.5	72	24.79981	17.35961	15.49932	89282.79	92%	85%	3.7
38	2.9	72	23.11511	16.17999	14.44652	84150.65	93%	81%	3.1
39	4.48	72	30.09279	21.06327	18.80706	105232.5	87%	59%	4.68
40	3.42	72	37.90548	26.53103	23.6896	130887.9	93%	37%	3.62
41	1.66	72	38.24627	26.77027	23.9027	130148.5	90%	48%	1.86
42	2.46	72	30.49186	21.34306	19.05658	105054.6	97%	67%	2.66
43	2.14	72	45.01102	31.50422	28.13025	156671.3	90%	22%	2.34
44	2.14	72	33.90092	23.72907	21.18708	116781.3	93%	59%	2.34
45	1.86	72	40.61302	28.42662	25.38179	141448.7	93%	41%	2.06
46	2.36	72	39.38971	27.57003	24.61722	132100.7	93%	37%	2.56
47	2.9	72	36.43869	25.50468	22.77297	125900.8	92%	44%	3.1
48	1.98	72	36.67925	25.6733	22.92338	125815.6	95%	48%	2.18
49	2.38	72	39.27935	27.49277	24.54825	134107.2	92%	37%	2.58
50	2.18	72	35.81404	25.06736	22.38265	125818.5	92%	44%	2.38
AVG	2.482	72	35.85145	25.0939	22.40602	124061.2	0.924	0.500741	2.682

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APPENDIX G. T-TESTS FOR RESOURCES AND DEAD AGENTS

Resource X

t-Test: Two-Sample Assuming Unequal Variances						
	Case 3	*Case 4*	*Case 4*	*Case 5*	*Case 3*	*Case 5*
Mean	37.82033	37.04863	37.04863	35.85145	37.82033	35.85145
Variance	21.56655	14.29112	14.29112	34.53358	21.56655	34.53358
Observations	50	50	50	50	50	50
Hypothesized Mean Difference	0		0		0	
df	94		84		93	
t Stat	0.911266		1.211496		1.858754	
P(T<=t) one-tail	0.182243		0.114551		0.033112	
t Critical one-tail	1.661226		1.663197		1.661404	
P(T<=t) two-tail	0.364486		0.229102			
t Critical two-tail	1.985523		1.98861			

Resource Y

t-Test: Two-Sample Assuming Unequal Variances						
	Case 3	*Case 4*	*Case 4*	*Case 5*	*Case 3*	*Case 5*
Mean	26.47160	25.93165	25.931651	25.093	26.471605	25.0939
Variance	10.56351	6.999508	6.9995084	16.914	10.563517	16.914
Observations	50	50	50	50	50	50
Hypothesized Mean Difference	0		0		0	
df	94		84		93	
t Stat	0.911049		1.2113653		1.8584453	
P(T<=t) one-tail	0.182299		0.1145761		0.0331344	
t Critical one-tail	1.661225		1.6631966		1.6614036	
P(T<=t) two-tail	0.364599		0.2291522		0.0662688	
t Critical two-tail	1.985523		1.9886096		1.9858018	

Resource Z

t-Test: Two-Sample Assuming Unequal Variances						
	Case 3	*Case 4*	*Case 4*	*Case 5*	*Case 3*	*Case 5*
Mean	23.63644	23.154182	23.154182	22.40602	23.636446	22.40602
Variance	8.423056	5.5814688	5.5814688	13.48736	8.4230562	13.48736

Observations	50	50	50	50	50	50
Hypothesized Mean Difference	0		0		0	
df	94		84		93	
t Stat	0.911246		1.2114870		1.8587257	
P(T<=t) one-tail	0.182248		0.1145529		0.0331143	
t Critical one-tail	1.661225		1.6631966		1.6614036	
P(T<=t) two-tail	0.364496		0.2291059		0.0662286	
t Critical two-tail	1.985523		1.988609		1.9858018	

Distance Away from WP5

t-Test: Two-Sample Assuming Unequal Variances						
	Case 1	*Case 2*	*Case 2*	*Case 3*	*Case 3*	*Case 4*
Mean	2.952	2.6784	2.6784	2.4816	2.4816	2.4224
Variance	0.506906	0.434218	0.434218	0.638283	0.638283	0.193725
Observations	50	50	50	50	50	50
Hypothesized Mean Difference	0		0		0	
df	97		95		76	
t Stat	1.994241		1.343728		0.458926	
P(T<=t) one-tail	0.024466		0.091119		0.323798	
t Critical one-tail	1.660715		1.661052		1.665151	
P(T<=t) two-tail	0.048933		0.182237		0.647597	
t Critical two-tail	1.984723		1.985251		1.991673	
	Case 4	*Case 5*	*Case 3*	*Case 5*	*Case 2*	*Case 5*
Mean	2.4224	2.482	2.4816	2.482	2.6784	2.482
Variance	0.193725	0.43238	0.638283	0.43238	0.434218	0.43238
Observations	50	50	50	50	50	50
Hypothesized Mean Difference	0		0		0	
df	86		95		98	
t Stat	-0.53261		-0.00273		1.491825	
P(T<=t) one-tail	0.297839		0.498912		0.069479	
t Critical one-tail	1.662765		1.661052		1.660551	
P(T<=t) two-tail	0.595678		0.997825		0.138957	
t Critical two-tail	1.987934		1.985251		1.984467	

Blue Dead

t-Test: Two-Sample Assuming Unequal Variances				
	Case 1	*Case 2*	*Case 2*	*Case 3*
Mean	0.481481	0.542222	0.542222	0.402963
Variance	0.059405	0.039067	0.039067	0.016721
Observations	50	50	50	50
Hypothesized Mean Difference	0		0	
df	94		84	
t Stat	-1.3687		4.169068	
P(T<=t) one-tail	0.087177		3.7E-05	
t Critical one-tail	1.661226		1.663197	
P(T<=t) two-tail	0.174355		7.4E-05	
t Critical two-tail	1.985523		1.98861	
	Case 3	*Case 4*	*Case 4*	*Case 5*
Mean	0.402963	0.445185	0.445185	0.500741
Variance	0.016721	0.014249	0.014249	0.03008
Observations	50	50	50	50
Hypothesized Mean Difference	0		0	
df	97		87	
t Stat	-1.69652		-1.86582	
P(T<=t) one-tail	0.046497		0.032718	
t Critical one-tail	1.660715		1.662557	
P(T<=t) two-tail	0.092994		0.065436	
t Critical two-tail	1.984723		1.987608	

Red Dead

	Case 1	*Case 2*	*Case 2*	*Case 3*
Mean	0.725	0.856667	0.856667	0.966333
Variance	0.009311	0.003073	0.003073	0.000595
Observations	50	50	50	50
Hypothesized Mean Difference	0		0	
df	78		67	
t Stat	-8.36631		-12.8045	
P(T<=t) one-tail	9.17E-13		5.67E-20	
t Critical one-tail	1.664625		1.667916	

	Case 1	*Case 2*	*Case 2*	*Case 3*
P(T<=t) two-tail	1.83E-12		1.13E-19	
t Critical two-tail	1.990847		1.996008	
	Case 3	*Case 4*	*Case 4*	*Case 5*
Mean	0.966333	0.946667	0.946667	0.924
Variance	0.000595	0.00102	0.00102	0.001068
Observations	50	50	50	50
Hypothesized Mean Difference	0		0	
df	92		98	
t Stat	3.459855		3.507594	
P(T<=t) one-tail	0.000411		0.000342	
t Critical one-tail	1.661585		1.660551	
P(T<=t) two-tail	0.000821		0.000684	
t Critical two-tail	1.986086		1.984467	

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